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Aquatic Plant Control Research Program

Physical and Environmental Characteristics of Experimental Ponds at the Lewisville Aquatic Ecosystem Research Facility

by R. Michael Smart, John D. Madsen,
Joe R. Snow, WES

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AScI Corporation

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Prepared for Headquarters, U.S. Army Corps of Engineers

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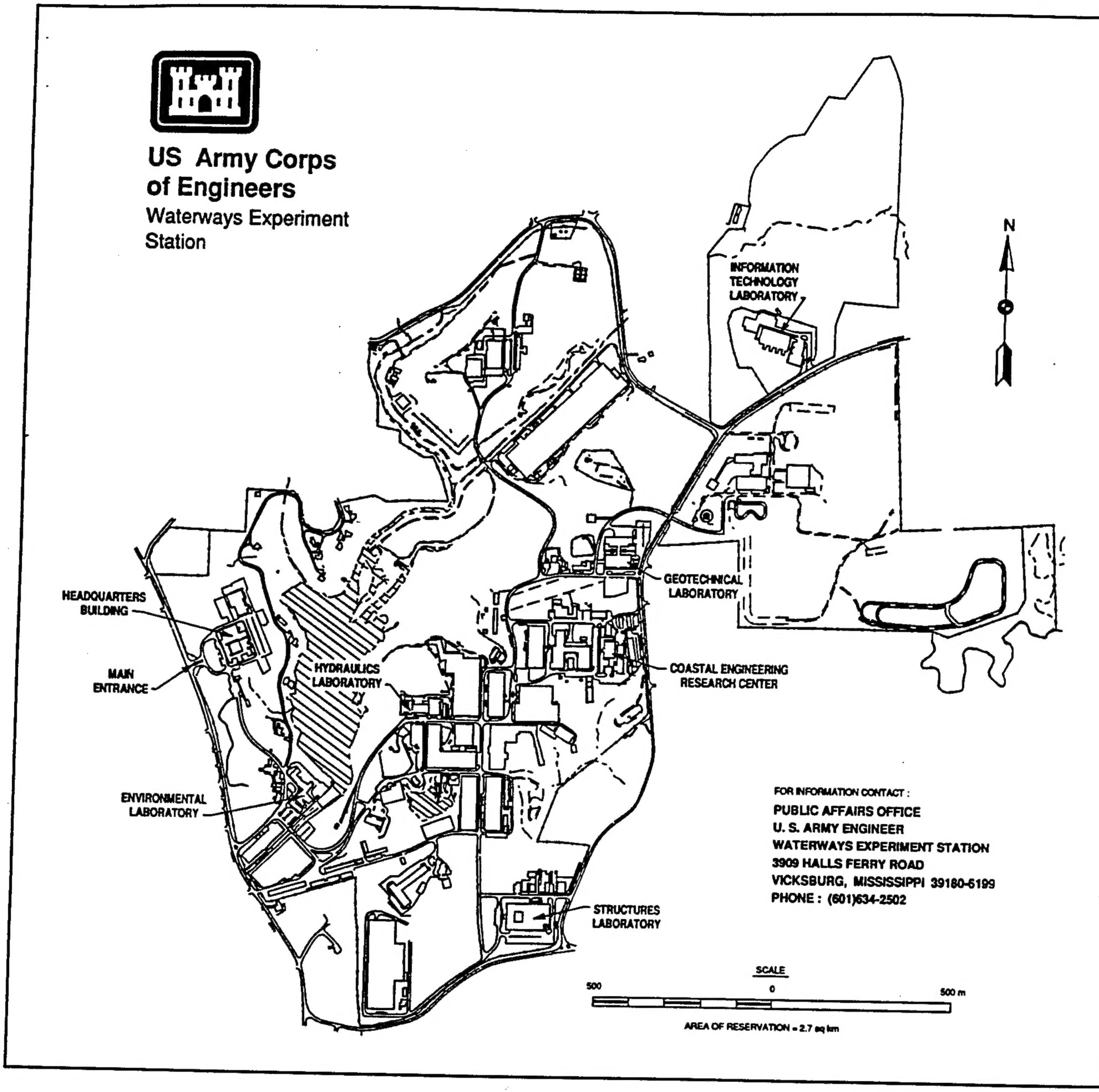

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32733. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (USAEWES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation Number 96X3122, Construction General. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP) by Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for APCRP. Technical Monitor during this study was Ms. Denise White, HQUSACE.

Principal Investigator for this study was Dr. R. Michael Smart, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. The report was written by Dr. Smart and Messrs. Gary O. Dick and David R. Honnell, AScI Corp., Mr. John D. Madsen, EPED, and Mr. Joe R. Snow, Lewisville Aquatic Ecosystem Research Facility, Lewisville, TX. Technical assistance was provided by contract students Michael Crouch, Aleida Eubanks, David Holland, and Kimberly Mauermann. The report was reviewed by Drs. Robert Doyle and Kurt D. Getsinger, EPED, EL.

This investigation was performed under the general supervision of Dr. Richard E. Price, Chief, EPEB, Mr. Donald L. Robey, Chief, EPED, and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of the WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

The Lewisville Aquatic Ecosystem Research Facility (LAERF), located in Lewisville, TX, (33° N latitude, 97° W longitude) was developed by the Corps of Engineers' (CE) Aquatic Plant Control Research Program (APCRP) to support studies of the biology, ecology, and management of aquatic plants. The primary reason for the development of this experimental pond facility is the need for an intermediate-scale research environment to bridge the gap between small-scale laboratory, greenhouse studies, and large-scale field tests. Pond-scale testing and research are important intermediate steps in the development of technology for the solution of aquatic plant problems in large reservoir systems.

The pond facility, a former Texas Parks and Wildlife Department fish hatchery, is located on federally owned land just below the dam of Lewisville Lake, a Corps reservoir which serves as the source of water supplied to the ponds. The land is controlled by the U.S. Army Engineer District, Fort Worth, and the facility is operated by the U.S. Army Engineer Waterways Experiment Station's (WES) Environmental Laboratory under a 25-year, renewable agreement.

The LAERF includes research greenhouses, raceways, and several fiberglass tank and mesocosm systems, in addition to experimental ponds. A description of these facilities and the research being conducted in them is provided in an APCRP Bulletin (Smart and Decell 1994). The historical development of the LAERF is described in a series of articles (Smart 1990, 1991a,b, 1992a,b, 1993, 1994a,b). The objective of this report is to describe the physical and environmental characteristics of experimental ponds at the LAERF in order to characterize their suitability for conducting aquatic plant research. This information will be of use to scientists and engineers conducting research at the facility, as well as to interested readers of scientific reports on this research.

2 Meteorological Conditions

An onsite meteorological station (Omnidata, Salt Lake City, UT) collects environmental data to support studies conducted at the LAERF. This system monitors temperatures of the air (1 m above ground) and soil (10 cm deep), solar radiation, photosynthetically active radiation (PAR), wind speed and direction, and rainfall. The system became operational in January, 1990. Meteorological data collected at LAERF are available on an hourly or daily basis (Table 1). Many experimental ponds have also been equipped with sensors and datalogging equipment to record temperatures of the water column (at various depths) and the sediment (-10 cm). These instruments also provide redundant records of air temperature and solar radiation as backups for the meteorological station (Table 1). Data reports can be provided in a variety of formats on request.

Daily maximum, minimum, and average air temperatures for 1992 are provided in Figure 1. Similar meteorological data are available for 1990, 1991, and 1993. We include in this report only the data for 1992 to correspond with an intensive period of water quality monitoring in selected ponds. These water chemistry data will be provided in a later section of the report. Daily average air temperatures approached 30 °C during June, July, and August, and several freezes were recorded in January, March, November, and December. Seasonal patterns of air temperature are qualitatively similar for the other 3 years recorded. Spring, summer, and fall temperatures are generally suitable for the growth of a large variety of both introduced and native aquatic plant species. Less cold-hardy species, such as waterhyacinth (*Eichornia crasippes*), require protection during colder winters.[1]

Daily maximum PAR levels during 1992 are provided in Figure 2.

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[1] John D. Madsen. 1994. Unpublished data.

Table 1
Availability of Environmental Data for Different Ponds at the Lewisville Aquatic Ecosystem Research Facility

Period and Study/Location	Parameter	Hourly Reports	Daily Reports
Jan 1990-present	Air temperature	average	min, max, average
Meteorological station	Soil temperature	average	min, max, average
	Wind speed	average	min, max, average
	Wind direction	vector average	vector average
	Rainfall	average	sum, max, max time
	Solar radiation	average	max
	PAR	average	max
Feb 1991-Nov 1993	Air temperature	average	min, max, average
Waterhyacinth phenology	Water temperature, surface	average	average
Ponds 16 & 17	Water temperature, middepth	average	average
	Solar radiation	average	max
	PAR	average	max
Mar 1991-Nov 1992	Water temperature, surface	average	
Biocontrol studies, Ponds 40 & 41	Water temperature, middepth	average	
Jul 1991-present	Water temperature, surface		min, max, average
Long-term competition study	Water temperature, middepth		min, max, average
Pond 26	Water temperature, bottom		min, max, average
	Sediment temperature		average
Jan 1992-Dec 1993	Air temperature	average	min, max, average
Eurasian watermilfoil phenology	Water temperature, surface	average	average
Ponds 14 & 15	Water temperature, middepth	average	average
	Solar radiation	average	max
	PAR	average	max
Jul 1992-Nov 1993	Water temperature, surface	average	min, max, average
Short-term competition study	Water temperature, middepth	average	min, max, average
Pond 27	Sediment temperature	average	min, max, average
Jun 1993-present	Water temperature, surface	average	
Biocontrol study, Ponds 20 & 21	Water temperature, middepth	average	

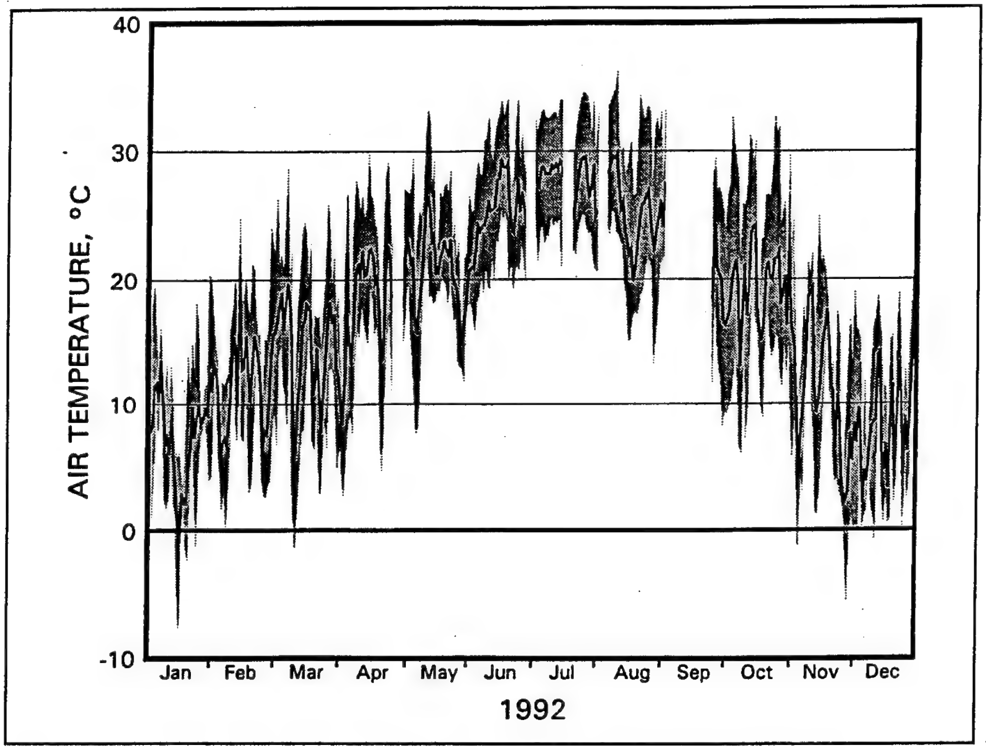

Figure 1. Daily minimum, maximum, and average air temperatures recorded at LAERF during 1992. The shaded area denotes the daily range in temperature

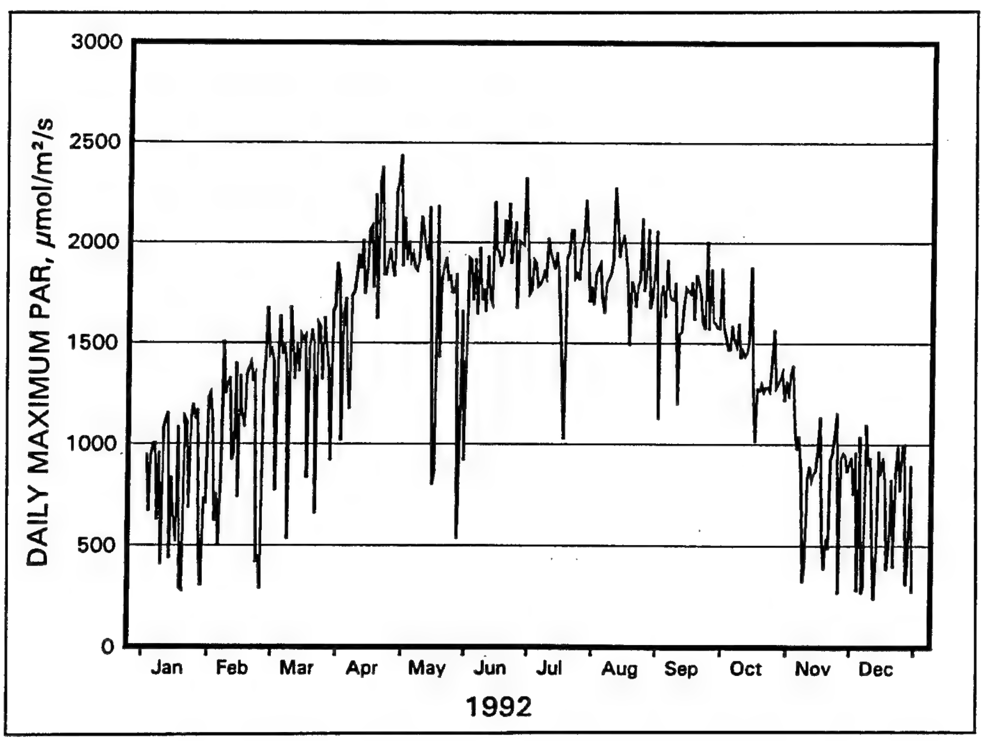

Figure 2. Daily maximum photosynthetically active radiation (PAR) levels recorded at LAERF during 1992

3 Physical Characteristics of the Ponds

Pond Morphometry

Most of the ponds are rectangularly shaped and are aligned in a north-south or east-west orientation (Figure 3). The ponds range in size from 0.17 to 0.73 hectares (Table 2). Thirty-five rectangular ponds have a water surface area between 0.25 and 0.32 hectares and a volume between 2,600 and 3,700 m^3. Blocks of similarly sized, shaped, and oriented ponds facilitate replication of pond studies. The relatively small dimensions of the ponds (generally 30-40 m by 70-80 m) and the ability to drive support vehicles on all four surrounding levees allow easy access to the ponds for sampling and observation.

Pond levees were originally constructed during the 1950's with 1:4 (vertical:horizontal) interior slopes (Figure 4). The pond bottoms and levees were lined with a locally available clay and covered with soil. Pond bottoms were constructed with a 2-percent grade (2:100) toward the center line and a 1-percent grade (1:100) toward the drain box (Figure 4, Photo 1) where both filling and draining occur. Some changes in slopes have occurred over the years since construction, but these design specifications are useful in estimating pond volumes and depths. Depth contours of a representative pond are shown in Figure 5. Most of the ponds are approximately 2 m deep at the deepest end and have average depths of around 1.0 m (Table 2). These dimensions make them suitable for conducting research with submersed, free-floating, and emergent vegetation.

Temperature and Light

Daily average surface, bottom, and sediment temperatures for a representative pond during 1992 are provided in Figure 6. Because of their shallow depth and frequent mixing by wind, the LAERF ponds do not exhibit strong thermal stratification. Surface water temperatures tend to track average air temperatures fairly closely (Smart, Snow, and Dick 1992). Daily average surface water temperatures are plotted with daily average air temperatures for

1992 in Figure 7. As indicated earlier for air temperatures, water temperatures are quite suitable for the growth of many native and exotic species.

The underwater light climate of the LAERF ponds is evaluated with LiCor underwater quantum sensors and dataloggers. Light intensities measured at the surface and at 50-cm depth intervals over a 2-day period in a typical pond are provided in Figure 8. The water in vegetated ponds is quite clear, allowing for high light levels and favorable growing conditions for submersed aquatic plants. This high water clarity is attributable to the filtering effect of submersed aquatic plants and to the low levels of phytoplankton in the water column. Total suspended solids are quite low (Chapter 6) and chlorophyll-a levels are generally less than 5 mg/m^3.[1]

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[1] David Honnell. 1994. Unpublished data.

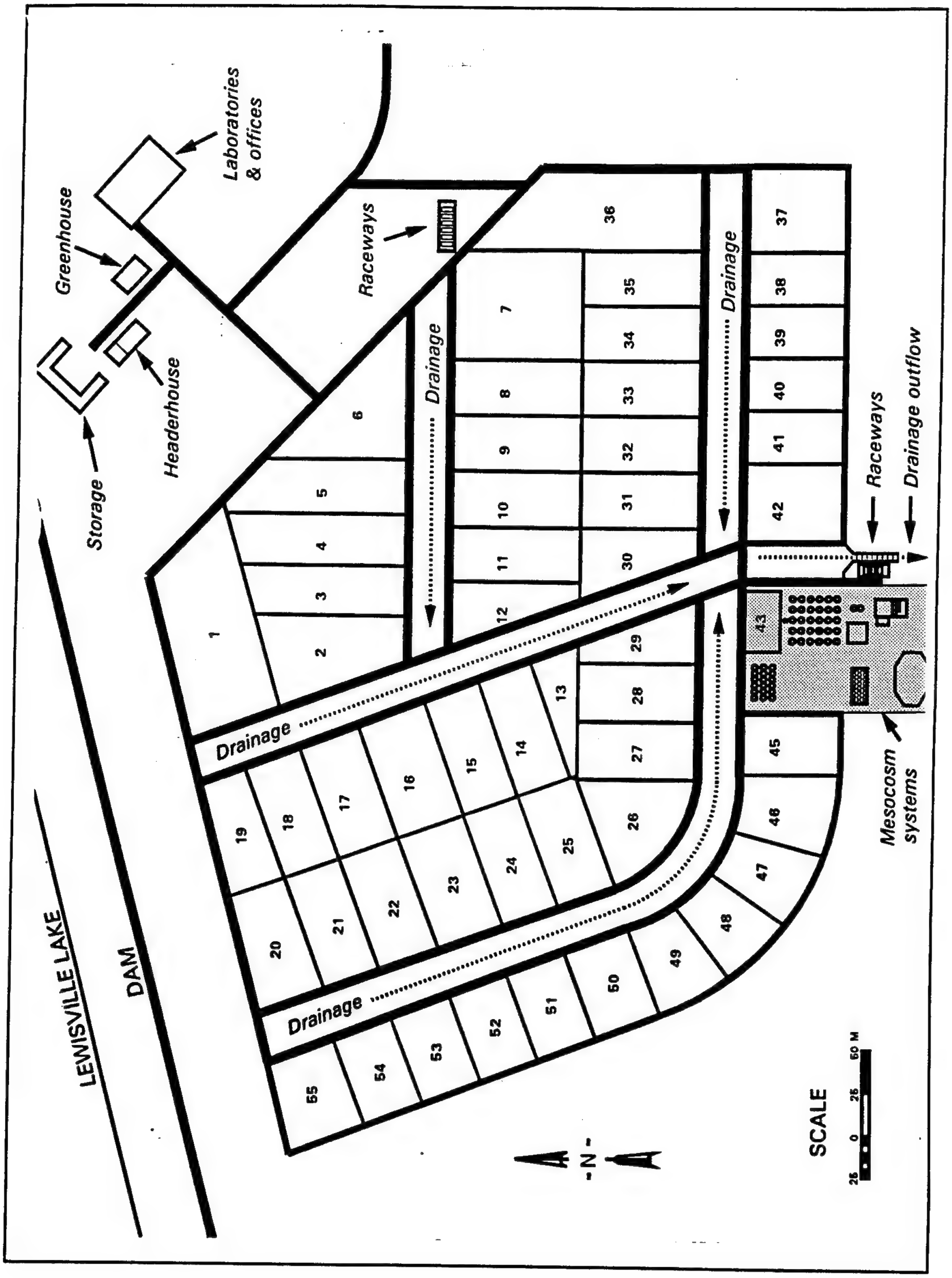

Figure 3. Plan view of the Lewisville Aquatic Ecosystem Research Facility

Table 2
Physical Characteristics of Experimental Ponds

Pond ID	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Width* (m)	Length* (m)
1**	0.70	8,336	1.3	59	124
2**	0.43	4,128	1.0	49	95
3	0.35	3,746	1.1	34	111
4	0.37	4,174	1.1	34	119
5	0.36	3,897	1.1	34	114
6**	0.46	5,501	1.3	79	122
7	0.58	7,686	1.4	72	85
8	0.28	2,606	1.0	35	85
9	0.28	2,606	1.0	35	85
10	0.28	2,667	1.0	35	85
11	0.28	2,667	1.0	35	85
12**	0.28	2,794	1.0	35	85
13**	0.17	1,552	0.9	24	79
14	0.27	2,550	0.9	37	79
15	0.32	3,555	1.1	43	79
16	0.32	3,555	1.1	43	79
17	0.32	3,555	1.1	43	79
18	0.25	2,381	1.0	34	79
19	0.26	2,459	1.0	35	79
20	0.27	2,978	1.1	37	79
21	0.32	3,713	1.2	43	79
22	0.32	3,685	1.2	43	79
23	0.32	3,713	1.2	43	79
24	0.32	3,734	1.2	43	79
25	0.33	3,762	1.2	44	79
26**	0.39	4,285	1.2	82	98
27	0.32	3,762	1.2	43	79
28	0.32	3,734	1.2	43	79

(Continued)

* Rectangular dimensions
** Ponds are irregularly shaped

Table 2 (Concluded)

Pond ID	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Width* (m)	Length* (m)
29**	0.15	1,315	0.9	21	79
30**	0.27	2,812	1.1	37	79
31	0.26	2,595	1.0	35	79
32	0.26	2,595	1.0	35	79
33	0.27	2,687	1.0	37	79
34	0.27	2,687	1.0	37	79
35	0.27	2,609	1.0	37	79
36**	0.73	8,129	1.2	55	140
37	0.35	4,021	1.2	55	67
38	0.21	1,981	1.0	34	67
39	0.21	1,981	1.0	34	67
40	0.21	1,981	1.0	34	67
41	0.21	1,981	1.0	34	67
42	0.29	2,860	1.1	46	67
43	0.13	1,835	1.4	46	31
44	--	--	--	--	--
45	0.25	2,577	1.1	40	67
46	0.25	3,006	1.2	40	67
47	0.25	2,974	1.2	40	67
48	0.25	3,006	1.2	40	67
49	0.25	2,974	1.2	40	67
50	0.25	2,577	1.1	40	67
51	0.25	2,606	1.1	40	67
52	0.25	2,577	1.1	40	67
53	0.25	2,606	1.1	40	67
54	0.25	2,577	1.1	40	67
55	0.33	3,317	1.1	52	67
Sum	16.27	176,642	--	--	--
Mean	0.30	3,212	1.1	41	79

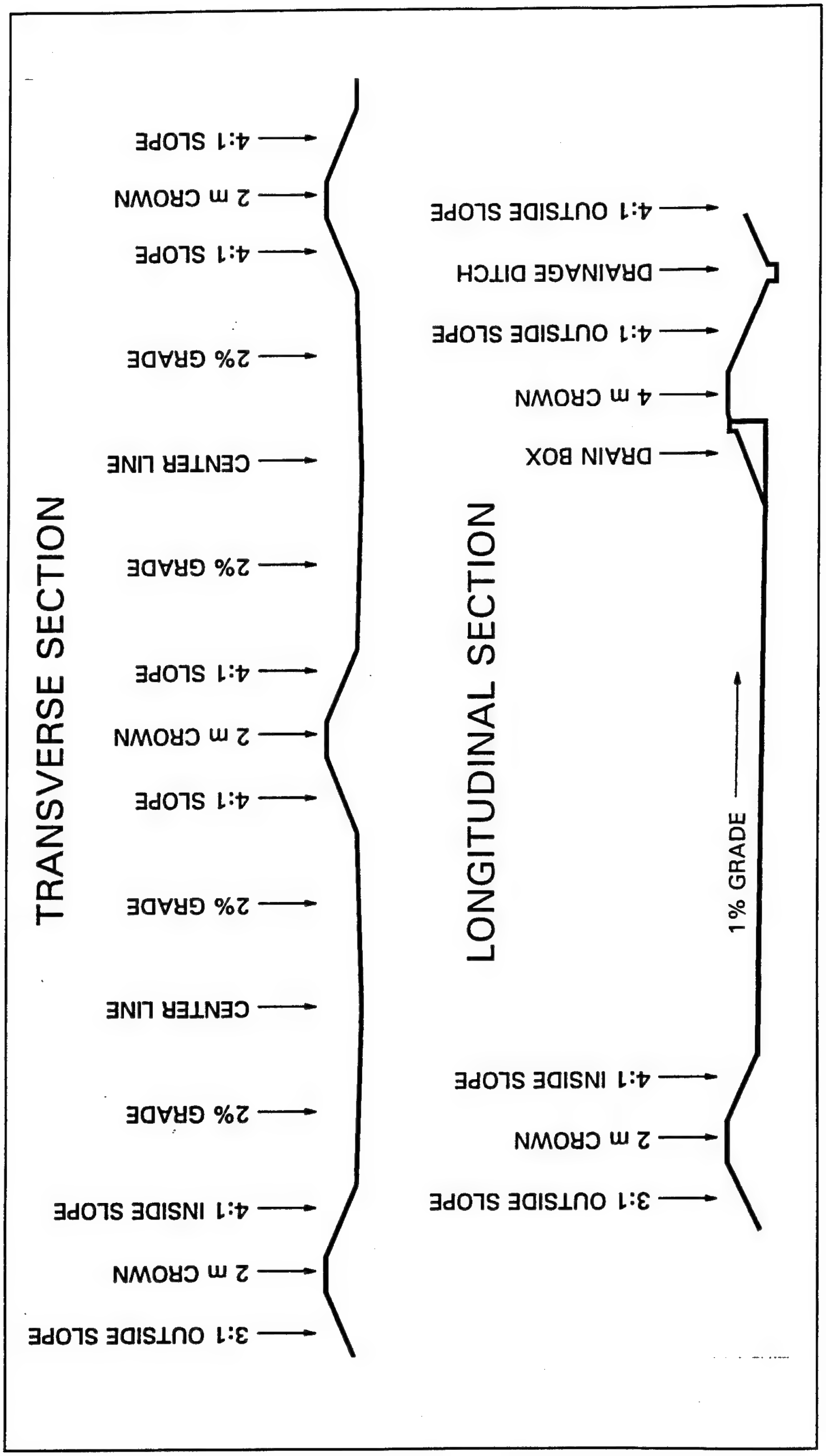

Figure 4. Design specifications of the LAERF ponds

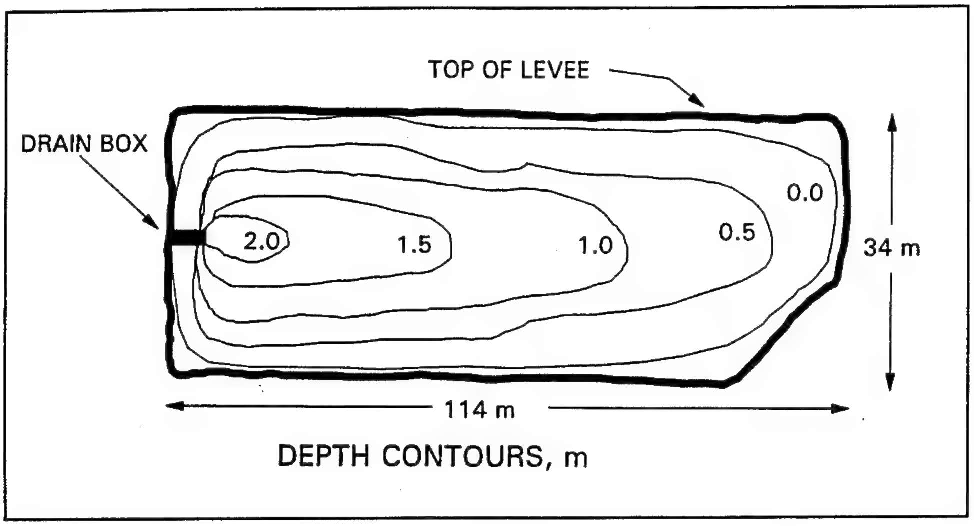

Figure 5. Depth contours (in meters) of a representative LAERF pond (#5)

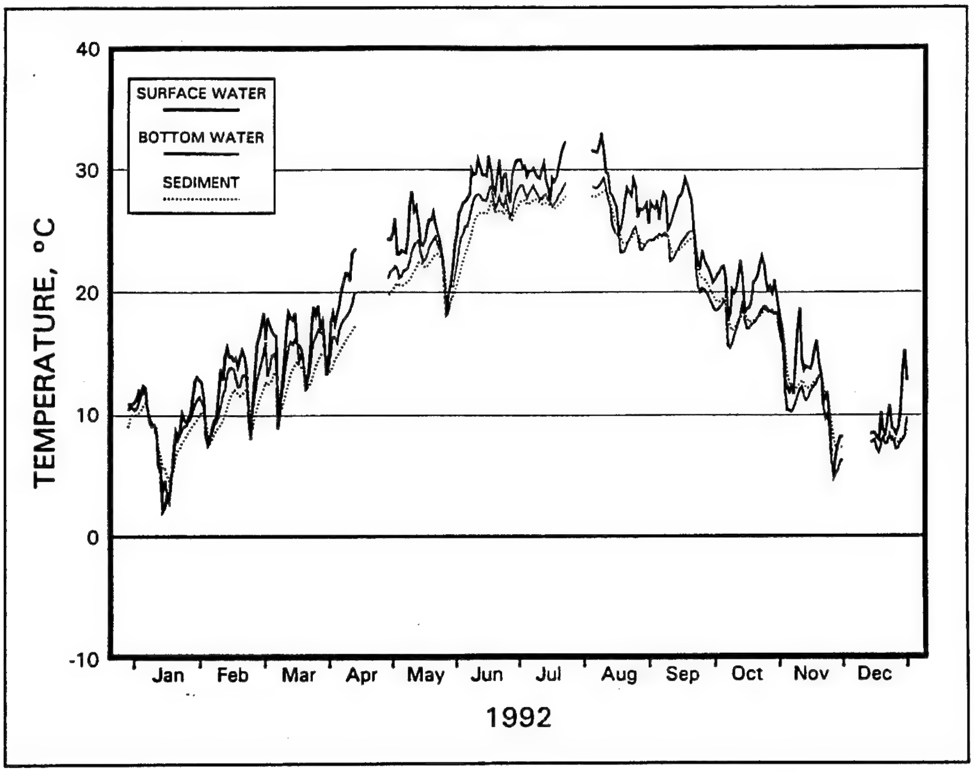

Figure 6. Daily average surface water, bottom water, and sediment temperatures recorded in Pond 27 during 1992

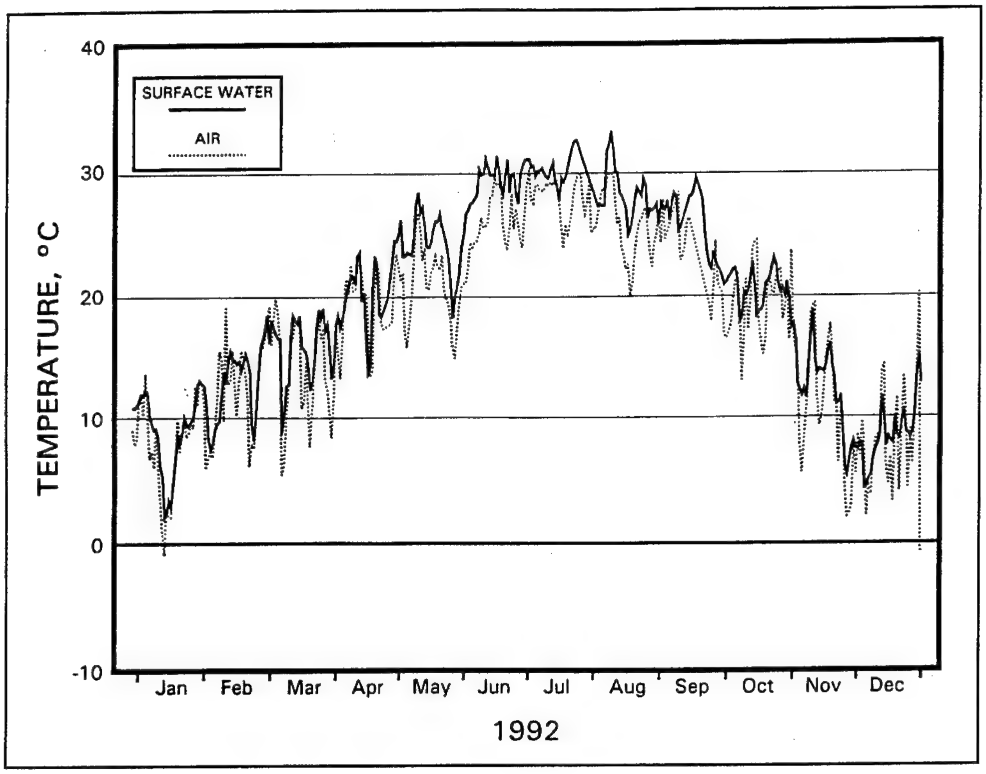

Figure 7. Daily average surface water and daily average air temperatures recorded in Pond 27 during 1992

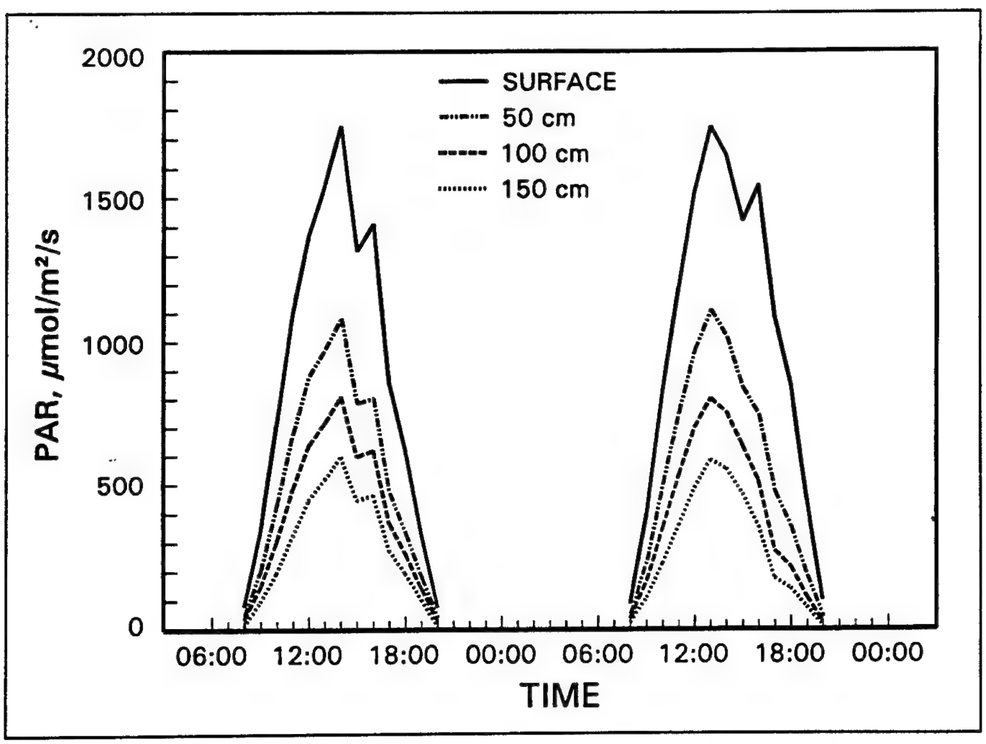

Figure 8. Diurnal changes in photosynthetically active radiation (PAR) over a 2-day period (September 27 and 28, 1991) in Pond 26

4 Sediment Composition

Bulk Sediment Properties

The LAERF pond sediments have been analyzed for particle size, bulk density, moisture content, organic matter content, and interstitial and exchangeable nutrients (Table 3) during several ongoing investigations. Pond sediments are predominantly fine-textured, consisting of 28 percent sand, 33 percent silt, and 38 percent clay-sized particles as determined by the hydrometer method (Day 1956). Bulk density of the pond sediment (1.1 to 1.3 g dry mass/cm^3) and organic matter content (4 to 6 percent of the dry weight) are within favorable ranges for rooted submersed aquatic plants (Barko and Smart 1986).

Table 3
Sample Preparation, Preservation, and Analytical Techniques for Sediment Analysis

Parameter	Bottle	Preservation	Method[1]
Bulk Density, Moisture Content	Whirlpacks or sealed plastic containers	Refrigeration, dark	Volumetric weighing, drying at 105 °C
Organic Matter Content			Combustion at 550 °C
Interstitial Water Nutrients and Metals			Refrigerated centrifugation at 4 °C, storage and analysis as per Table 4
Exchangeable Nutrients			1 N HCl extraction, storage and analysis as per Table 4
Particle Size			Hydrometer method

[1] *Methods of soil analysis*. (1989). 2nd ed., No. 9, Parts 1 and 2.

Sediment Fertility

To ascertain the suitability of the LAERF ponds for growing submersed aquatic plants, a greenhouse investigation of the fertility of pond bottom sediments was conducted. Samples of the upper 15 cm of the pond bottom were collected from 10 randomly selected ponds. Within-pond variability was investigated by sampling at two locations in two of the ponds. All of the ponds except one (Pond 7) had been previously drained for 1 or more years and supported terrestrial vegetation. Pond 7 had been filled several months prior to sampling, and the bottom remained partially flooded. Sample 7A was obtained from the flooded area while Sample 7B was collected from the dry portion of the pond. Samples were placed in plastic bags and transported to WES for analysis and bioassay. A sediment sample was also obtained from Brown's Lake on the grounds at WES. This fertile sediment, which has been used in several studies (Barko and Smart 1986; Barko et al. 1988; Smart, Barko, and McFarland 1994) and for culturing submersed aquatic plants, was included in the bioassay for reference purposes.

Except for Sample 7A, pond substrates were pulverized in a large hammermill and then rewet to saturation with deionized water. Samples were held in a saturated state for over 1 week prior to experimentation. A composite sediment sample was prepared by combining all of the LAERF sediments in equal proportions. The possibility that plant growth may have been limited by N or P was checked by amending the composite with N, and with both N and P.

Pond substrates were placed in 1-L containers, planted with three apical tips (10-cm length) of hydrilla, and randomly assigned to 1,200-L fiberglass tanks containing a submersed aquatic plant culture solution (Smart and Barko 1985). The experimental solution lacked N and P, thus the plants were dependent on the sediment substrate for their supply of these elements. Plants were grown at a temperature of 25 °C for a period of 5 weeks. Roots and shoots were harvested, washed, dried, and weighed to determine dry weight biomass.

Hydrilla biomass production on the pond substrates was variable, spanning a seven-fold range. Maximal growth was obtained on substrate 7A, the sediment sample collected from the flooded pond (Figure 9). Growth on all other substrates was generally 50 percent or less than that obtained on the reference sediment. Biomass production on the various pond substrates was highly correlated with both exchangeable NH_4 (Smart, unpublished data)[1] and interstitial water NH_4 concentrations (Figure 10), providing evidence that the growth of hydrilla was limited by N on most, if not all, of the pond substrates. As expected, biomass production on the composite substrate was within the range exemplified by the other substrates (Figure 11A). Addition of N (as NH_4Cl) to the composite substrate stimulated an 80-percent increase

[1] R. Michael Smart. 1993. Unpublished data.

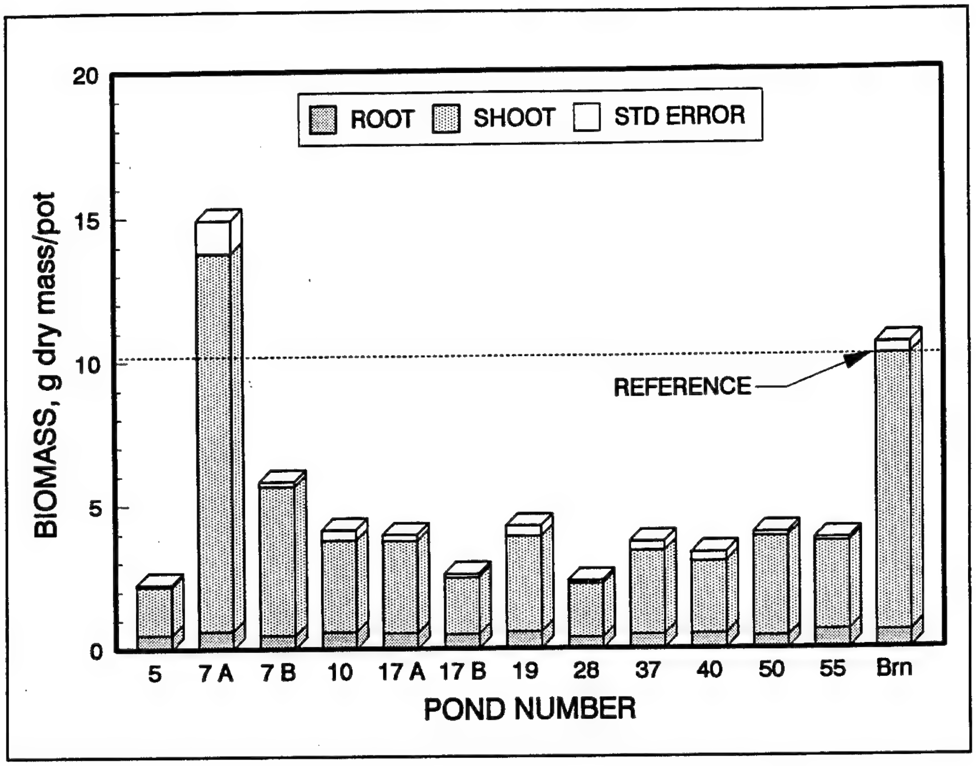

Figure 9. Biomass response of hydrilla grown on different LAERF pond sediments and a reference sediment (Brown's Lake, Mississippi). Values are means of four replications

in growth, confirming that sediment N availability was limiting growth in the bioassay. Addition of P to the sediment substrate did not affect growth. The lack of a growth response to P, even after N stimulated growth, indicates that P was not limiting growth on the composite substrate.

To verify the results of this simple bioassay for sediment fertility, a pond containing fertilized and unfertilized plots was prepared. The entire bottom of the pond was rototilled to break up terrestrial vegetation and to prepare a smooth substrate for planting. Commercial fertilizer ($(NH_4)_2SO_4$) was added to the N-fertilized plots and incorporated by rototilling. Apical tips of hydrilla were planted on 30-cm centers in fertilized and control plots in August 1990. The pond was flooded to a depth of 1 to 1.2 m and the plants were allowed to grow for 10 weeks prior to harvest in October 1990.

Hydrilla grew rapidly in both control and N-fertilized plots. In the control plots, hydrilla attained nearly 300 g dry shoot mass/m^2 (Figure 11B). These control plots also supported a native macrophyte community consisting of *Najas guadalupensis* and the macroalga *Chara vulgaris*. These species contributed nearly 100 g dry shoot mass/m^2 to the biomass of the population, for a total of nearly 400 g dry mass/m^2. This level of biomass production is typical of eutrophic systems in the United States. The N-fertilized plots produced 700 g dry shoot mass/m^2, and virtually all of this was hydrilla. The large increase in growth promoted by N fertilization clearly indicates that

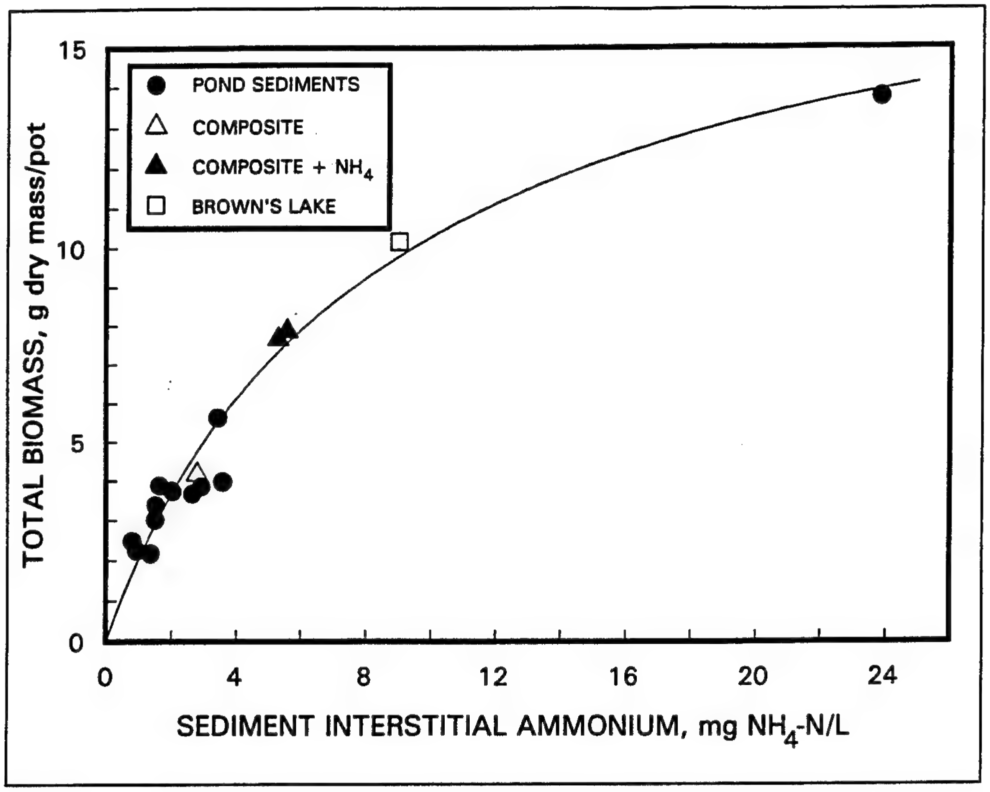

Figure 10. Biomass of hydrilla in relation to sediment interstitial water NH_4-N concentrations. Values of biomass are means of four replications. Values of sediment N are means of duplicate samples

submersed macrophyte growth in the LAERF ponds is likely to be limited by the availability of sediment N.

Observed variations in the growth of hydrilla on different pond substrates in the bioassay are attributable to differences in the content or availability of sediment N. Subsequent investigations have since shown that N availability (in the water column) is also limiting the growth of free-floating aquatic plants (Madsen 1993a,b). A specific application of the information provided in these studies is that differing amounts of aquatic plant biomass can be achieved by varying the quantity of N added to the substrate during pond preparation (for submersed plants), or to the water column (for free-floating plants).

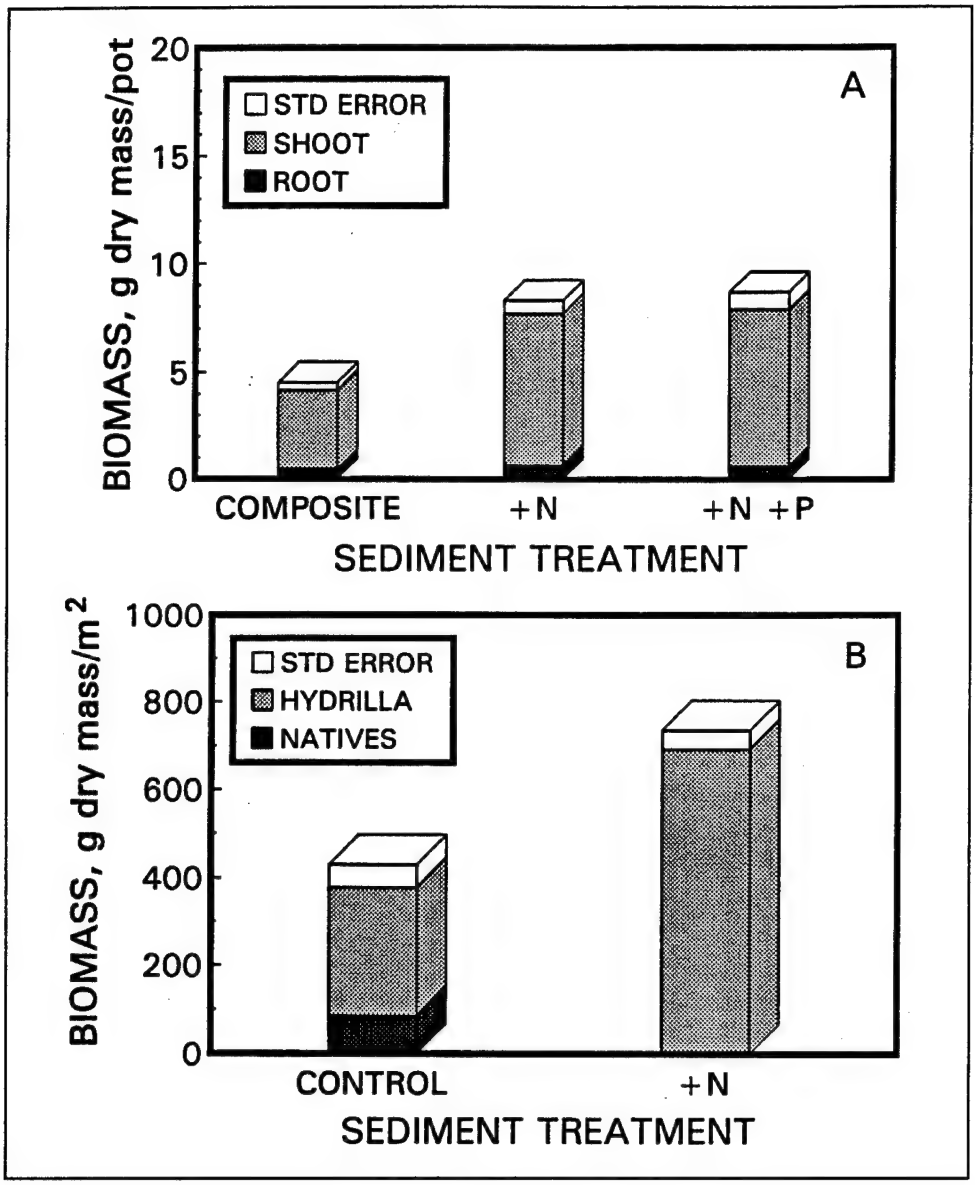

Figure 11. A. Biomass response of hydrilla grown on a composite pond sediment and the same sediment amended with NH_4Cl (+N) or NH_4Cl and KH_2PO_4 (+N+P). Values are means of four replications. B. Biomass response of hydrilla and native species in control and N fertilized plots in Pond 26. Values are means of four replications

5 Biotic Considerations

The Sediment Seedbank

Since the ponds have been in use for over 30 years, they have developed a characteristic flora that persists as seeds/spores in the sediment. Characteristic plant species include several that are adapted to varying periods of flooding and draining, such as the macroalga, chara (*Chara vulgaris*), and the rooted, vascular plants, American pondweed (*Potamogeton nodosus*), horned pondweed (*Zannichellia palustris*), and southern naiad (*Najas guadalupensis*). Chara and southern naiad are the dominant species and are well represented in the seed bank of all the ponds. In an evaluation of the seedbank contained in the surface sediment of one pond, Dick[1] counted over 7,000 chara spores and approximately 200 southern naiad seeds/m^2 pond sediment surface. The presence of this extant plant community must be considered when designing pond studies. Although these species do not interfere with the establishment of exotic, weedy species,[2] their presence may affect establishment of some native species (Smart 1991b; Doyle and Smart 1993). To minimize possible disruptive effects of these species on the establishment of desired native species, we have been developing both cultural and chemical methods for suppressing their growth (Dick and Smart 1992).

Turtles, Fish, and Other Aquatic Animals

In addition to the extant vegetation in the ponds, several species of aquatic animals are commonly found at the LAERF. Some of these may affect aquatic plant establishment and growth. For example, recent investigations have shown that red-eared turtles (*Trachemys scripta elegans*) may impact newly establishing submersed aquatic plant communities (Smart 1991b, 1992b). By selectively feeding on preferred species such as *Vallisneria americana* (Dick and Smart, unpublished data),[3] these predominantly herbivorous turtles may hinder establishment efforts. Several attempts at establishing

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1 Gary Dick. 1992. Unpublished data.
2 R. Michael Smart. 1992. Personal observation.
3 Gary Dick and R. Michael Smart. Unpublished data.

new populations of *Vallisneria* and even a nonpreferred species such as *Potamogeton nodosus* have been severely hampered by turtle herbivory.[1] Where a concern for herbivory exists, turtle trapping (alone or in combination with turtle-exclusion fencing) can be used to eliminate this potential problem.

Fish frequently survive the journey through the water-supply system from Lewisville Lake. Species commonly introduced to ponds in this manner include bluegill (*Lepomis macrochirus*), white crappie (*Poxomis annularis*), and common carp (*Cyprinus carpio*). Although not of large concern to most aquatic plant research undertaken at the facility, some research, such as fish-plant interaction investigations, requires that no "wild" fish become established in a pond. This is accomplished by draining ponds to eliminate existing populations and screening the inflow water to individual ponds with fine-mesh aquacultural netting to prevent reintroduction of fish. Also, since large populations of bluegill and carp may seriously impact small water bodies, all ponds expected to be in operation for more than one growing season are filled with screened water.

Several other species of aquatic organisms may also be of concern to aquatic plant researchers. Crayfish (*Procambarus* spp. and *Orconectes* spp.) have impacted aquatic plant communities by both direct consumption and clipping (Lodge and Lorman 1987; Chambers et al. 1990). Tadpole shrimp (*Apus* spp.) frequently disturb bottom sediments causing high levels of turbidity, and they may feed directly on young macrophyte shoots in newly filled and planted ponds.[1] The introduction of small numbers of largemouth bass (*Micropterus salmoides*) seems to keep crayfish numbers in check in the LAERF culture ponds and may be useful in managing persistent tadpole shrimp populations.

Herbivorous animals such as nutria (*Myocastor coypus*) can severely damage populations of emergent aquatic plants (Fuller et al. 1985) and populations of this herbivore require monitoring and occasional control. From an operations standpoint, both nutria and beaver (*Castor canadensis*) can be disruptive, due to their tendencies to burrow through pond levees and block drainage systems. Although both nutria and beaver are present in the vicinity of the LAERF, no serious problems have been encountered with either of these species to date.

Algal Epiphytes, Phytoplankton, and Floating Algal Mats

Phosphorus fertilizer is frequently added to stimulate algal blooms in ponds used to raise fish (Boyd 1979). Since phytoplankton forms the base of the food chain, increased algal production leads to an increase in fish production. Under aerobic (oxidizing) conditions, phosphate (PO_4) is strongly adsorbed to

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[1] Gary Dick. 1992. Personal observation.

ferric oxyhydroxides (FeOOH), and much of the added P is lost from the water column during the precipitation of these insoluble iron (Fe) compounds (Stumm and Morgan 1981, Wetzel 1975). Precipitation of $CaCO_3$, which commonly occurs during photosynthesis of algae or submersed vascular plants in hard water, can also remove PO_4 from the water to the sediment (Otsuki and Wetzel 1972, Kleiner 1988). As a consequence of these geochemical processes, much of the added P ultimately ends up in the sediment. This large store of P can persist for many years after P additions have ceased, steadily contributing P to the water column. This occurrence has been termed "internal loading" (Cooke et al. 1977) and has been a major concern of those charged with reducing eutrophication. Since the ponds were used to raise fish for approximately 30 years, the sediments are a potentially very large source of P.

Since rooted submersed aquatic plants derive much of their P from the sediment (Barko and Smart 1980, Smart and Barko 1985, Howard-Williams and Allanson 1981), high concentrations of P in pond sediments may benefit rooted submersed aquatic plants (Barko and Smart 1986, Barko, Adams, and Clesceri 1986, Chapter 4 of this report). The concern is that P contributed to the water column by these high sedimentary reserves might cause excessive growth of phytoplankton, epiphytes, or floating algal mats, all of which compete with submersed aquatic plants for light, inorganic carbon, and other essential nutrients. Excessive growth of algae interferes with the establishment of higher vegetation and may even eliminate submersed aquatic plants (Mulligan and Baranowski 1969, Sand-Jensen and Sondergaard 1981).

Rapidly growing and spreading weedy species such as hydrilla and Eurasian watermilfoil are generally little affected by the levels of algae growth sustained in the LAERF ponds. These plants rapidly grow to the water surface where they intercept much of the incident solar radiation (Haller and Sutton 1975, Titus and Adams 1979). These canopy-forming plants grow from terminal meristems and are also capable of rapid elongation under low-light conditions (Barko and Smart 1981, Stewart and Monteleone 1993). Except for a relatively brief period during initial establishment, these characteristics of weedy species make them less susceptible than most submersed aquatic plants to the effects of excessive growths of algae. During periods of active growth (mid-to-late spring and summer), weedy species actually suppress the growth of phytoplankton by forming a surface canopy which shades the water column. Thus, in spite of potentially high internal P loading, vegetated LAERF ponds do not support blooms of phytoplankton during the growing season, and summer chlorophyll-a levels are generally less than 5 mg/m^3 in hydrilla and Eurasian watermilfoil ponds.[1]

Since weedy species usually grow rapidly from terminal meristems located at the water surface, they are not usually affected by epiphytic algae.

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[1] David Honnell. 1993. Unpublished data.

However, during periods of senescence in the late summer and/or fall, deteriorating plant tissues in the canopy contribute to the growth of loosely attached/floating filamentous algal mats. Floating algal mats are also frequently observed in late winter and early spring, prior to the onset of active growth and canopy development. Filamentous algal mats do occasionally persist during the growing season and may sometimes interfere with the growth of some native species (Smart 1994b).

Some native species, such as *Vallisneria*, are much more susceptible to algal interference. *Vallisneria* spreads relatively slowly from stolons rather than from shoot fragments. Transplants or dormant winterbuds, which are much more difficult to obtain than shoot cuttings of weedy species, are usually required for establishment. For these reasons *Vallisneria* is more difficult to establish than hydrilla or Eurasian watermilfoil and requires a longer period of time for establishment (Doyle and Smart 1993). *Vallisneria* also distributes its biomass more uniformly throughout the water column (Titus and Adams 1979; Haller and Sutton 1975), has less capacity for elongation (Smart, Barko, and McFarland 1994), grows in a rosette form from a basal meristem (Titus and Stephens 1983), and has long-lived leaves which are accessible for colonization by epiphytes over a long period. These growth-form characteristics increase *Vallisneria*'s vulnerability to algal interference, and in conjunction with its heightened susceptibility during a long establishment phase, cause us to be concerned with the growth of algal epiphytes, phytoplankton, and floating algal mats. Successful establishment of *Vallisneria* in the LAERF ponds requires the use of fairly dense plantings of peat-potted transplants (Doyle and Smart 1993). However, once native plants (including *Vallisneria*) become successfully established, the potential of the pond for supporting excessive phytoplankton communities is reduced generally by less than 5 mg/m3, as evidenced by summer chlorophyll-a levels. Likewise well-established plants do not normally exhibit excessive epiphyte levels, and the plants do not appear to be adversely affected by the growth of epiphytic algae.

Although excessive algal growth is not anticipated to present problems for most pond users, we are currently evaluating methods for reducing P loading of the water column. We have very successfully used aluminum sulfate (alum) to precipitate P from pond water supplied to mesocosm tanks (Dick, Getsinger, and Smart 1993). Alum additions to ponds might also be used to remove P from the water column and to reduce subsequent fluxes of P from the sediment, thereby reducing the growth of unwanted algae.

6 Water Supply and Pond Water Quality

Water Supply and Pond Hydrology

The ponds and raceways are supplied with water from adjacent Lewisville Lake, a water supply-flood control reservoir constructed and operated by the Corps. The reservoir impounds the waters of the Elm Fork of the Trinity River and supplies water to the cities of Denton, Lewisville, and Dallas.

The ponds can be filled and drained independently, allowing investigators to control water levels and hydrologic regimes. Ponds are generally not operated under flow-through conditions, and water is supplied to the ponds only to fill the pond and to offset subsequent losses. Water levels in the ponds are monitored and maintained on a regular basis, however, to provide constant (± 2 cm) water levels, the ponds can be fitted with adjustable stand-pipes (Photo 2). Both filling and draining occurs at one end of the pond.

Water is lost from the ponds primarily through seepage and evaporation. The ponds, when full, have very little watershed, so direct rainfall is the only significant input of water other than through the fill pipe. Seepage rates vary from pond to pond depending on the integrity of the clay liner, water depth (head) of the pond, and the status of adjacent ponds (filled or drained). Net water losses to evaporation (after accounting for rainfall) are seasonal, with the greatest losses occurring during the summer months (Figure 12).

Water budgets are currently being constructed for selected ponds. These water budgets will be based on data obtained from several ponds and collected during different seasons. Fluorescent dye (rhodamine WT) and other conservative tracers will be used to estimate water exchange and net evaporation will be estimated from pan evaporation rates and water losses from a vinyl-lined water-supply pond.

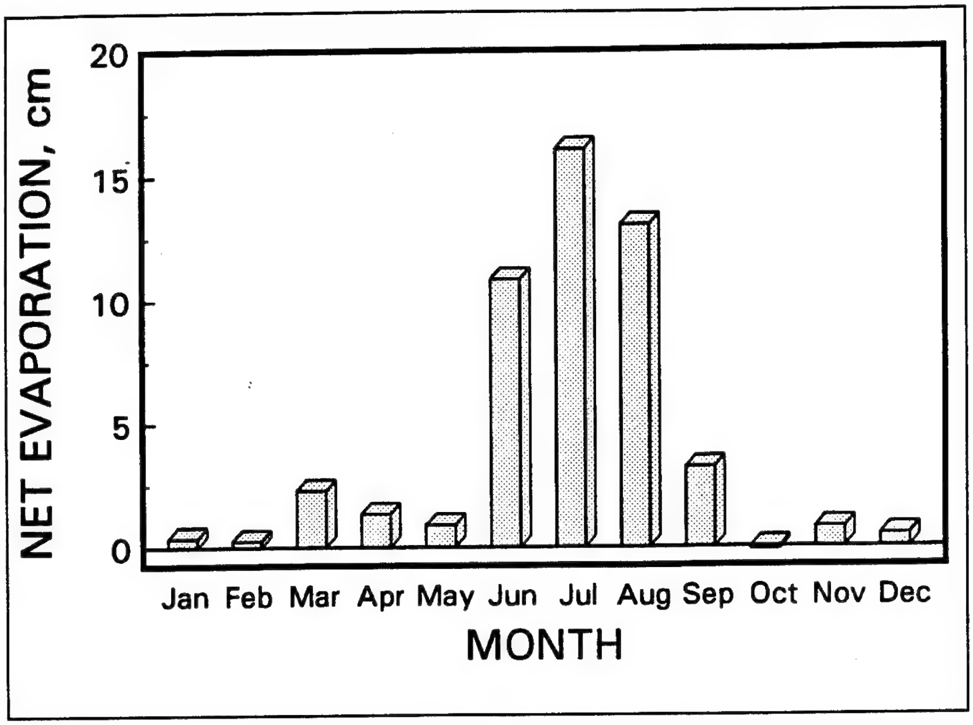

Figure 12. Long-term average monthly net evaporation rates for the north Texas area

Water Quality Monitoring Program

Water from both the inflow water-supply pipe and the outflow ditch (Figure 3) are sampled and analyzed on a regular basis (currently every 2 weeks) for several water quality parameters (Table 4). The objectives of this monitoring program are to characterize water provided to the research ponds and to monitor the quality of the water leaving the facility. Water in selected ponds, greenhouse tanks, raceways, and mesocosms are also regularly sampled and analyzed by LAERF analytical lab personnel to provide information (data) needed by investigators.

Sampling and analytical methodology

Each research pond is provided with a pier (5-m length) to provide access to the deepest portion of the pond to facilitate sampling and observation (Photo 3). The piers are located away from the inlet/outlet structure to minimize the influence of incoming water. Research ponds are also equipped with a permanent staff gauge for accurately recording water levels.

Routine water sampling of the ponds is performed by means of a depth-integrated water sampler designed to collect a column of water (approximately 3 L) from the upper 1 to 1.5 m of the water column. After collection, the sample is transferred to a clean (acid-washed) container, mixed, and distributed to appropriate sample bottles for preservation (Table 4). Grab

Table 4
Sample Preparation, Preservation, and Analytical Methods for Water Analysis

Parameter	Sample Type	Bottle	Preservation	Hold Time	Method[1]
Alkalinity	Raw water	Plastic, 500 ml	Refrigeration	<48 h	Electrometric titration
TSS				<7 d	Evaporation at 105 °C
Turbidity				<24 h	Nephelometric
Chlorophyll-a	Raw water	Plastic, 1 L	Refrigeration, dark	<30 d	Acetone extract, spectrophotometric
TP	Raw water	Plastic, 250 ml	Acidified to pH<2 (1:a H_2SO_4), refrigeration	<48 h	Persulfate digestion, spectrophotometric
NH_4-N				<48 h	Specific ion electrode
SRP	Filtered (0.45$_\mu$)	Plastic, 175 ml	Refrigeration	<24 h	Ascorbic acid, spectrophotometric
NO_3-N				<24 h	HPLC
Dissolved Metals (Na, K, Ca, Mg, Fe, Mn)	Filtered (0.45$_\mu$)	Plastic, 30 ml	Acidified to pH<2 with 1:1 HCl	<3 mo	Atomic absorption spectroscopy

[1] *Standard methods for the examination of water and wastewater.* (1989). 17th Ed.

sampling techniques are used for obtaining water samples from the inflow source and the outflow stream, as well as from greenhouse tanks and other areas that do not require integrated samples. In situ measurements of temperature, pH, dissolved oxygen, and conductivity are obtained with a Hydrolab Surveyor II at the time of water sample collection.

Methods for collection, preservation, and storage of samples, as well as methods of analysis (Table 4), are derived from Standard Methods, 17th edition (American Public Health Association, American Water Works Association, and Water Pollution Control Federation 1989). Quality control practices involve maintaining routine QA/QC charts for precision and accuracy. External standard audit samples are analyzed on a quarterly basis for each of the routine analyses performed. A QA/QC plan is available on request from the authors.

Water quality and chemical composition of the water supply

The chemical composition of the inflow water during the period May, 1991, through December, 1992, is provided as an example of the chemical composition of water supplied to the LAERF ponds.

Temperature of the inflow water (Figure 13A) ranged from 9.1 (January) to 28.6 °C (July). Inflow temperatures were generally within a few degrees

of 25 throughout the summer and then dropped steadily throughout the fall to between 10 and 15 °C during the winter months. After a minimum in January, inflow temperatures increased through the spring. Dissolved oxygen was not monitored on inflow samples. The pH of the inflow water (Figure 13B) ranged from 5.85 to 8.31. Alkalinity of the inflow exhibited little variation (Figure 13C) and was generally around 100 mg $CaCO_3$/L, with a range from 84 to 120 mg/L. Inflow conductivity was also fairly constant at around 300 μS/cm (Figure 13D).

Total phosphorus (TP) of the inflow (Figure 14A) averaged 50 μg P/L with a maximum of 186 μg P/L and a minimum <5 μg P/L. The average soluble reactive phosphorus (SRP) value for the inflow was 26 μg P/L, ranging from below detection (<5 μg P/L) to 84 μg P/L.

Nitrate nitrogen (NO_3-N) was very low during the summer periods and increased throughout the fall, winter, and spring (Figure 14B). Inflow NO_3-N concentrations averaged 0.29 mg/L, ranging from <0.02 to 1.50 mg N/L. Ammonium nitrogen (NH_4-N) in the inflow was generally low, averaging 0.05 mg N/L with a range of <0.02 to 0.22 mg N/L.

Turbidity of the inflow water was highest in the late fall to early winter (Figure 14C). Values ranged from 0.37 to 48 Nephelometric Turbidity Units (NTU). Turbidity was not always correlated with total suspended solids (TSS) which averaged 12 mg/L (Figure 14D). The range in inflow TSS was from <2 to 99 mg/L.

Calcium (Ca) was the major cation in the inflow water (Figure 15), followed by sodium (Na), magnesium (Mg), and potassium (K). Inflow Ca averaged 35 mg/L, ranging from 23.7 to 47.7 mg/L, while Na averaged 16.0 mg/L, ranging from 8.0 to 31 mg/L (Figure 15A). Inflow Mg ranged from 1.2 to 10.6 mg/L and averaged 5.4 mg/L; inflow K averaged 3.5 mg/L, ranging from 1.9 to 4.8 mg/L (Figure 15B).

Both trace metals, iron (Fe) and manganese (Mn), were usually analyzed at less than 0.1 mg/L (Figure 15C, 15D), except for occasional high values (0.74 mg Fe/L and 0.70 mg Mn/L).

Water quality and chemical composition of a vegetated pond

The chemical composition of Pond 37 (a *Hydrilla verticillata* stock culture pond), during the period May 1991 through December 1992, is provided as an example of the chemical composition to be expected in vegetated LAERF ponds. This pond was essentially a monoculture of hydrilla, with no other submersed aquatic plants evident, and only a narrow fringe of emergent vegetation. The pond was drained in February 1992 and kept dry for a brief period prior to reflooding. Except for this period, and for a few weeks afterward, the growth of hydrilla shoots filled much of the volume of the pond and covered the entire surface between June and November.

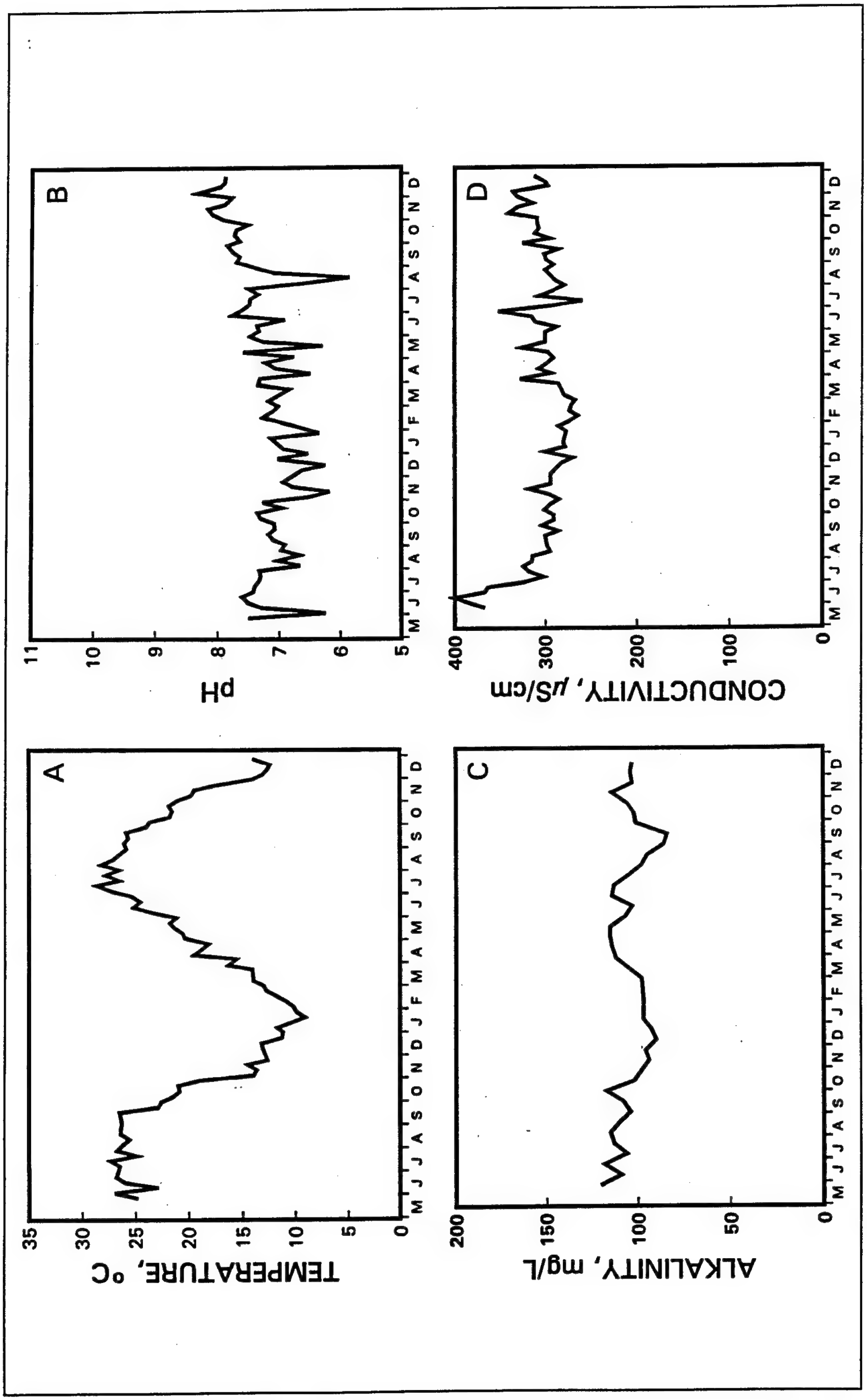

Figure 13. Water quality characteristics of the LAERF water supply: A. temperature, B. pH, C. alkalinity, and D. conductivity

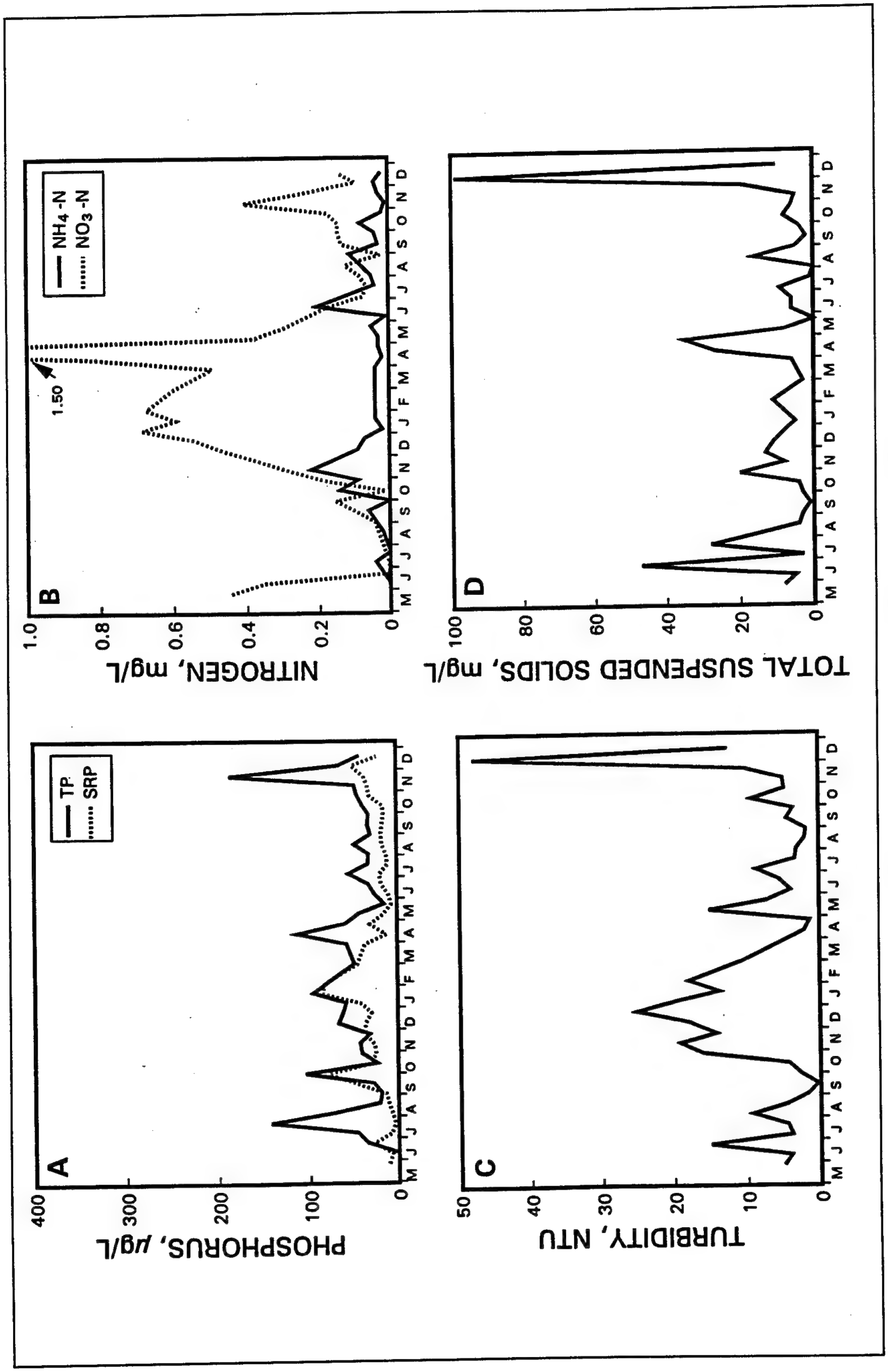

Figure 14. Composition of the LAERF water supply: A. total (TP) and soluble reactive phosphorus (SRP), B. ammonium (NH_4-N) and nitrate nitrogen (NO_3-N), C. turbidity, and D. total suspended solids (TSS)

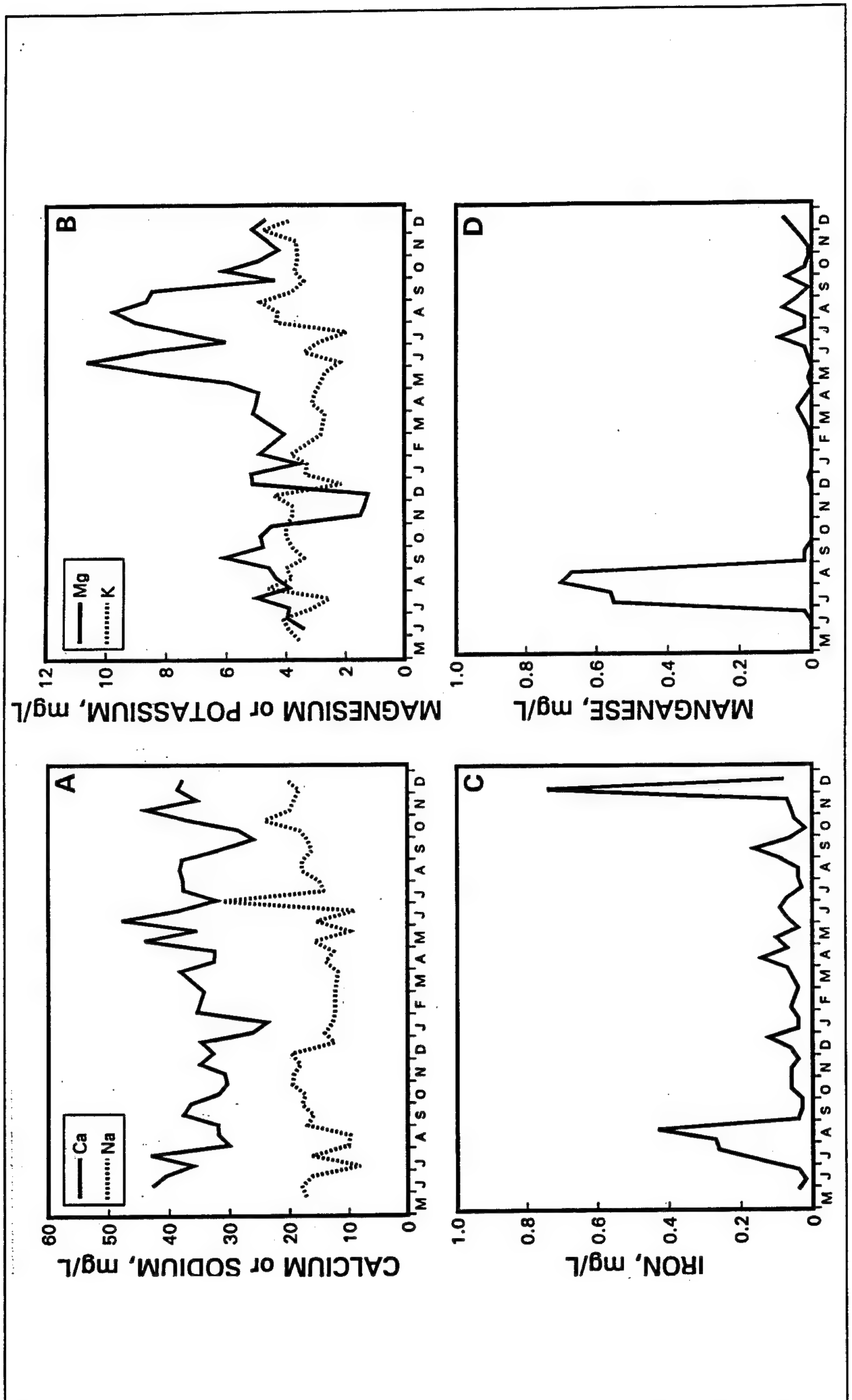

Figure 15. Metal ion concentrations of the LAERF water supply: A. calcium (Ca) and sodium (Na), B. magnesium (Mg) and potassium (K), C. iron (Fe), and D. manganese (Mn)

Surface water temperatures measured during water chemistry sampling events (Figure 16A) in the hydrilla pond (Pond 37) exhibited seasonal values similar to those presented for a typical pond earlier (Figure 6). Surface water temperatures in the hydrilla pond ranged from 3.9 to 31.6 °C.

Surface water pH in the hydrilla pond (Figure 16B) fluctuated over a wide range, from 6.4 to 10.2. These values are much higher than those in the inflowing water (Figure 13B), reflecting the photosynthetic activity of the plants, which lowers concentrations of both free carbon dioxide (CO_2) and bicarbonate (HCO_3^-), and raises pH. Similar values have been reported for hydrilla beds in Florida (Van, Haller, and Bowes 1976).

Dissolved oxygen levels in the surface water of the hydrilla pond (Figure 16C) fluctuated over a broad range, from 0.65 to 15.7 mg O_2/L. Although the mean dissolved oxygen level was 8.8 mg/L, we recorded many values below the 5.0 mg/L desirability threshold for warmwater fisheries (Boyd 1979). The occurrence of frequent low values of dissolved oxygen in the surface waters of this pond suggests that levels beneath the hydrilla canopy may have been much lower. Chronically low dissolved oxygen levels in ponds vegetated with exotic species have been previously reported and were related to the water surface area covered by the vegetation (Honnell, Madsen, and Smart 1992, 1993). Extensive surface coverage restricts the exchange of oxygen across the air-water interface, resulting in depressed dissolved oxygen levels.

Conductivity of the pond water (Figure 16D) was generally between 200 and 260 μS/cm. These values are lower, by an average of approximately 50 units, than those for the Lewisville Lake water supply, which remains near 300 μS/cm throughout the year (Figure 13D). Following a drawdown in late February 1992, the pond was refilled with Lewisville Lake water of higher conductivity. However, by the end of April 1992, conductivity of the pond water had, once again, declined from values around 350 to values near 200 μS/cm.

The spring 1992 decrease in the conductivity of water held in the hydrilla pond was accompanied by a decrease in alkalinity (Figure 16D). Precipitation of $CaCO_3$ during photosynthesis of hydrilla is the likely cause of the decrease in both alkalinity and conductivity. Alkalinity of the pond ranged between 70 and 100 mg $CaCO_3$/L and averaged 40 $CaCO_3$/L less than that of the Lewisville Lake water supplied to the pond.

Concentrations of TP and SRP in the pond (Figure 17A) were similar to or less than those of the inflow water (Figure 14A). Except for one event in the late summer when SRP reached 190 μg/L, the average SRP concentration in the hydrilla pond was 13 μg/L.

Both ammonium and nitrate concentrations in the hydrilla pond (Figure 17B) were generally less than 0.2 mg N/L. Average concentrations for NH_4-N and NO_3-N were 0.06 and 0.05 mg N/L, respectively.

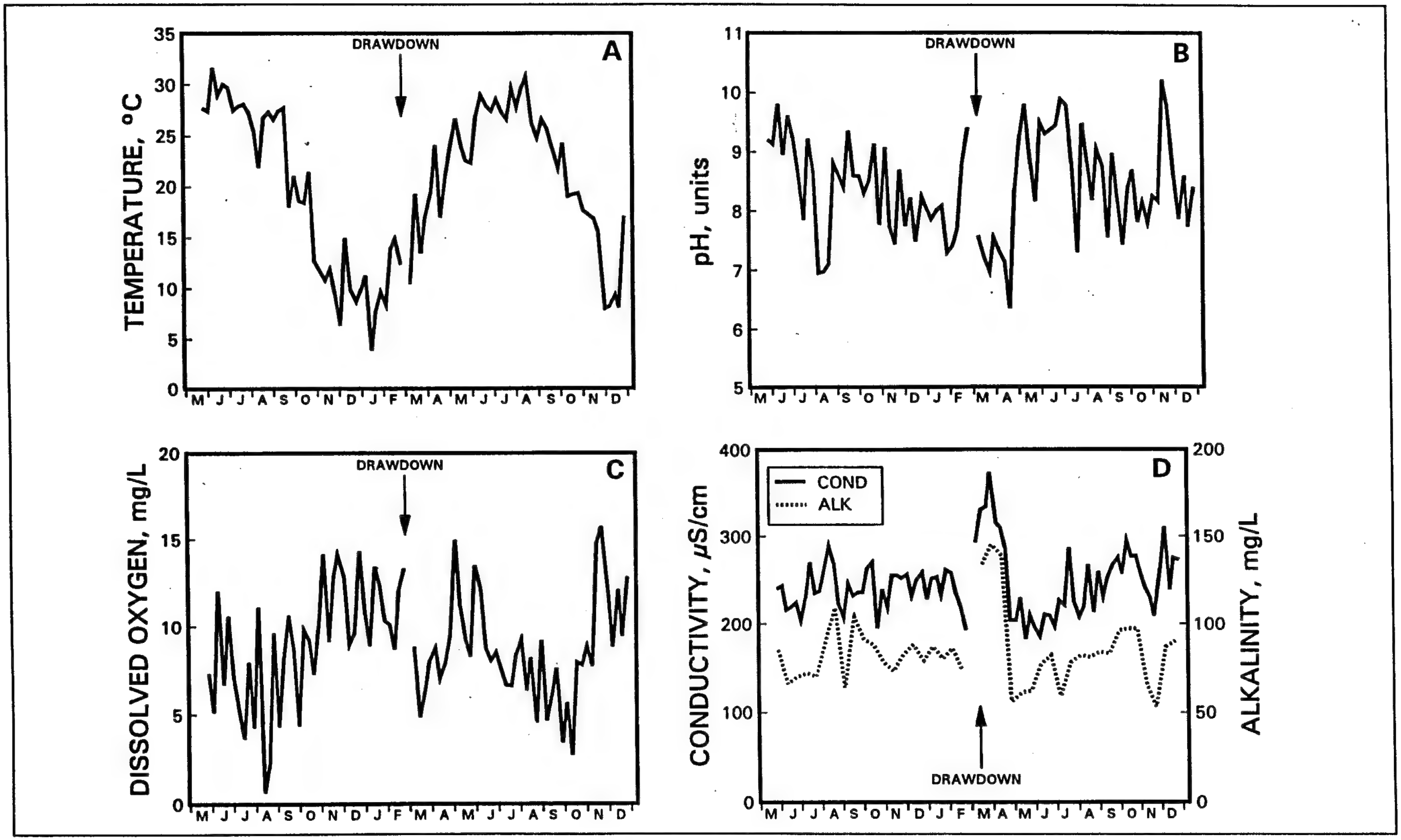

Figure 16. Water quality characteristics of a hydrilla culture pond (Pond 37): A. temperature, B. pH, C. dissolved oxygen, and D. conductivity and alkalinity

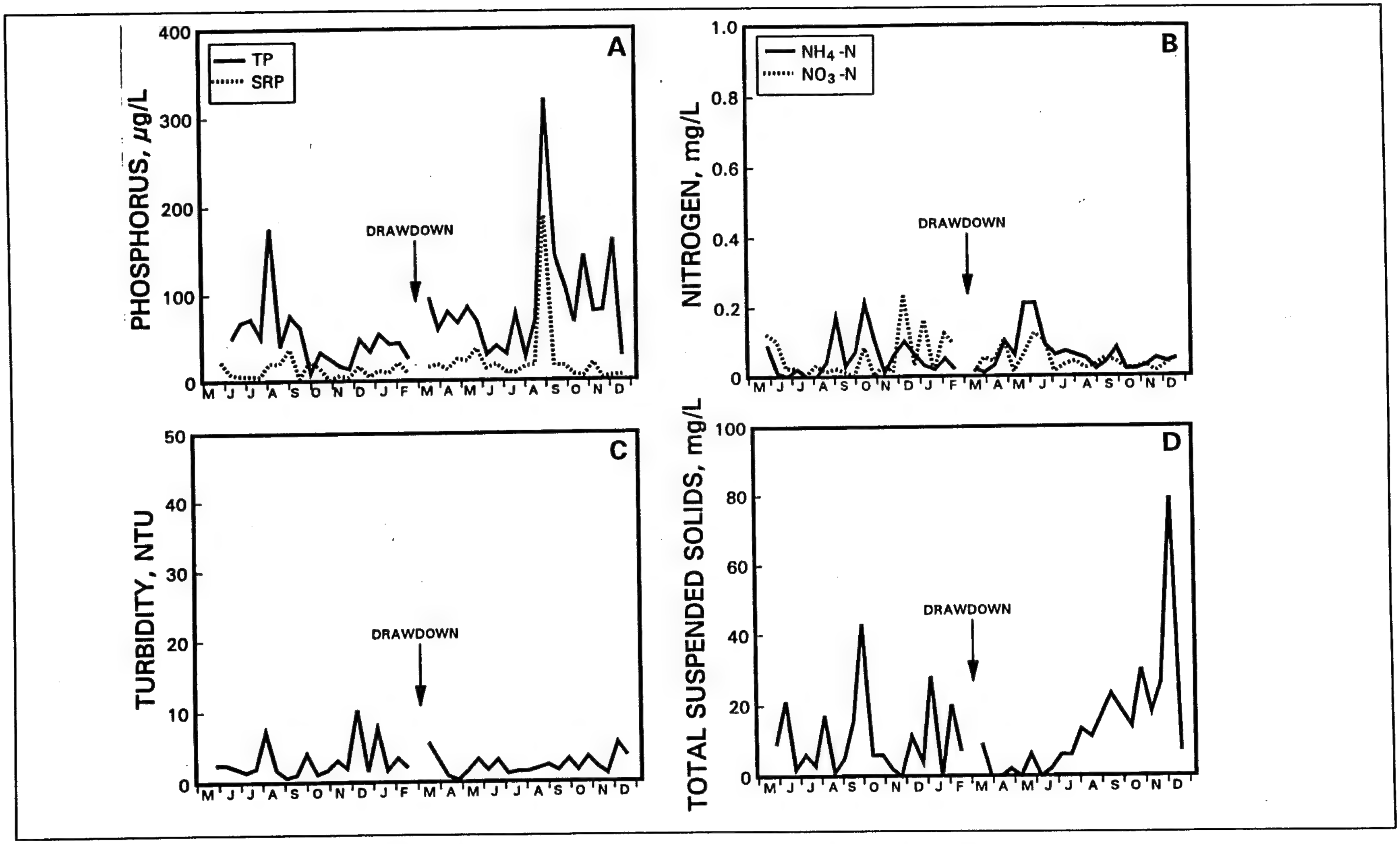

Figure 17. Composition of a hydrilla culture pond (Pond 37): A. total (TP) and soluble reactive phosphorus (SRP), B. ammonium (NH_4-N) and nitrate nitrogen (NO_3-N), C. turbidity, and D. total suspended solids (TSS)

Turbidity of the pond water (Figure 17C) was much lower than that of the Lewisville Lake water supplied to the pond (Figure 14C). The pond averaged 2.7 NTU with a range of 0.3 to 10.2. These low turbidity values are typical of vegetated water bodies and result from the filtering effect of the foliage on suspended matter, dampening of wind-generated mixing that can cause resuspension of deposited sediments, and stabilization of deposited sediments by root production. Like turbidity, TSS values for the pond (Figure 17D) were lower than those for the inflow water (Figure 14D). During the growing season, TSS levels of the pond surface water were generally 10 mg/L or less. Occasional values greater than 20 mg/L were observed, usually in the fall or winter when hydrilla was senescent or senescing.

Calcium concentrations in the pond (Figure 18A) were generally lower than those in the inflow water (Figure 15A). The rapid decrease in Ca during the spring of 1992 is likely due to the precipitation of $CaCO_3$ as discussed earlier. Concentrations of Ca in the pond surface water ranged from 17.7 to 55.6 mg/L with an average value of 28.7 mg/L.

Sodium concentrations in the pond (Figure 18A) exhibited little fluctuation and were generally quite similar to concentrations in the inflow (Figure 15A). Pond Na concentrations ranged from 8.7 to 24.3 mg/L with an average of 15.5 mg/L.

Magnesium concentrations in the pond (Figure 18B) were also quite similar to concentrations in the inflow (Figure 15B). Pond Mg concentrations ranged from 1.3 to 10.2 mg/L, with an average of 5.3 mg/L.

Potassium concentrations in the pond (Figure 18B) were also generally similar to concentrations in the inflow (Figure 15B). Pond K concentrations ranged from 0.9 to 7.8 mg/L, with an average of 3.3 mg/L.

Dissolved Fe and Mn concentrations in the surface water of the hydrilla pond (Figure 18C, 18D) averaged 0.10 and 0.08 mg/L, respectively. Iron ranged from 0.01 to 0.44 mg/L, and Mn ranged from <0.02 to 0.64 mg/L.

Diel water quality monitoring

In addition to routine water chemistry and water quality monitoring of the ponds, several studies at the LAERF have employed in situ water quality monitoring and logging equipment (Hydrolab Datasonde 3) to obtain more detailed measurements of the short- (diurnal) or long-term (seasonal) changes in water quality. As an example, we present a series of hourly water quality data obtained for 1-week monitoring periods during different seasons of the year. Data were obtained in pond 37, the same hydrilla culture pond selected for the water chemistry data. The Hydrolab DataSonde 3 units were calibrated in the laboratory prior to deployment in the pond. The datasondes were secured to the sampling/access pier (Photo 3) so that the probes were situated at a depth of approximately 20 cm below the water surface. After a

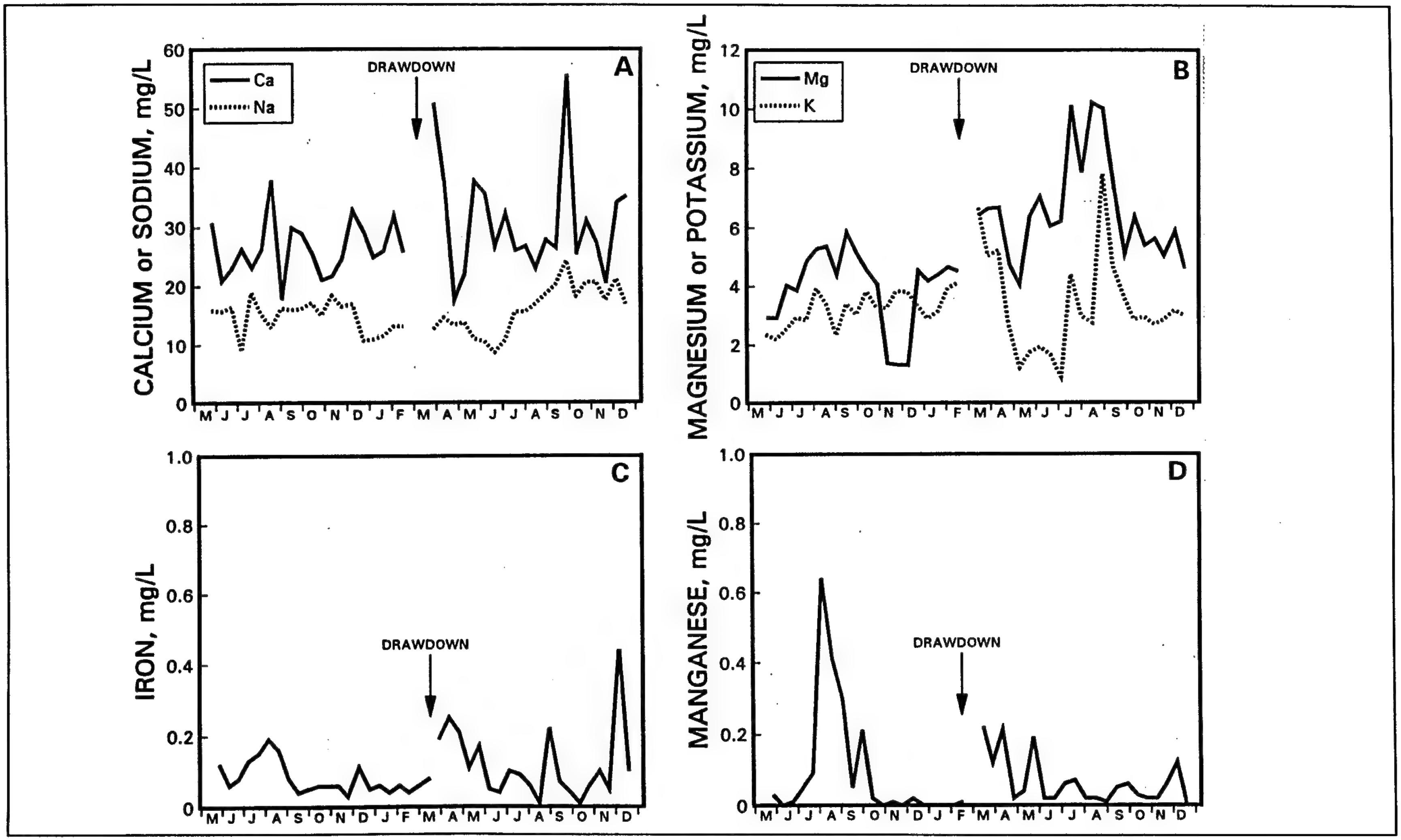

Figure 18. Metal ion concentrations of a hydrilla culture pond (Pond 37): A. calcium (Ca) and sodium (Na), B. magnesium (Mg) and potassium (K), C. iron (Fe), and D. manganese (Mn)

1-week period, the datasondes were returned to the laboratory, where their calibration was rechecked and the stored data downloaded. The datasondes were set to record temperature, pH, conductivity, and dissolved oxygen at hourly intervals.

Representative 1-week intervals were selected from each season (spring, summer, autumn, and winter) to demonstrate the seasonal and daily dynamics of water quality parameters in vegetated ponds. Since photosynthesis exerts strong effects on water quality and is dependent on light levels, hourly average PAR levels for each monitoring interval are presented in Figure 19 as an aid to interpretation of pond water quality changes. As expected, highest peak light levels were observed in summer, followed by spring, autumn, and winter. Although some of the days were partly cloudy, only 1 day (26 Nov 92) was so overcast that photosynthetic rates would have been seriously limited.

As shown earlier, daily average water temperatures correspond closely with daily average air temperatures over the long term (Figure 7). However, two important differences can be noted between diel cycles of water and air temperature (Figure 20). First, a significant lag time of 2 to 3 hr is evident between heating or cooling of air temperature and corresponding changes in water temperature. Second, although air temperatures may fluctuate up to 15 °C over a 24-hr period, water temperatures typically fluctuate less than 5 °C. As a result of the large difference in thermal mass between the overlying air and the water column, aquatic environments are generally more thermally stable than surrounding terrestrial environments.

During the spring and summer monitoring periods, when surface water temperatures were above 20 °C, regular diel variations in pH were observed (Figure 21A, 21B). Diel pH variations result from nighttime net respiratory CO_2 production, which lowers Ph, and net daytime photosynthetic CO_2 (or HCO_3^-) consumption, which increases Ph, (Van, Haller and Bowes 1976; Lucas 1983; Maberly and Spence 1983; Smart and Barko 1986). Similar diel pH changes have been observed in other submersed plant communities (Van, Haller, and Bowes 1976; Carter et al. 1988; Ondok, Pokorny, and Kivet 1984).

Summer diel pH cycles include rapid morning increases followed by sharp, two-unit declines in pH from midday to late afternoon (Figure 21B). These rapid declines in pH are likely the result of $CaCO_3$ precipitation which results in a redistribution of carbon species (Smart and Barko 1986). At night (or at depth), precipitated $CaCO_3$ can be redissolved by influxes of atmospheric or respiratory CO_2, regenerating the supply of dissolved inorganic carbon for photosynthesis the following day.

During autumn and winter, pH did not vary in a predictable diel pattern (Figure 21C, 21D). The absence of regular diel cyles in Ph indicates that hydrilla photosynthesis was limited during these monitoring periods, probably due to the combined effects of low water temperatures (below 20 °C) and the senescent state of hydrilla shoots during autumn and winter.

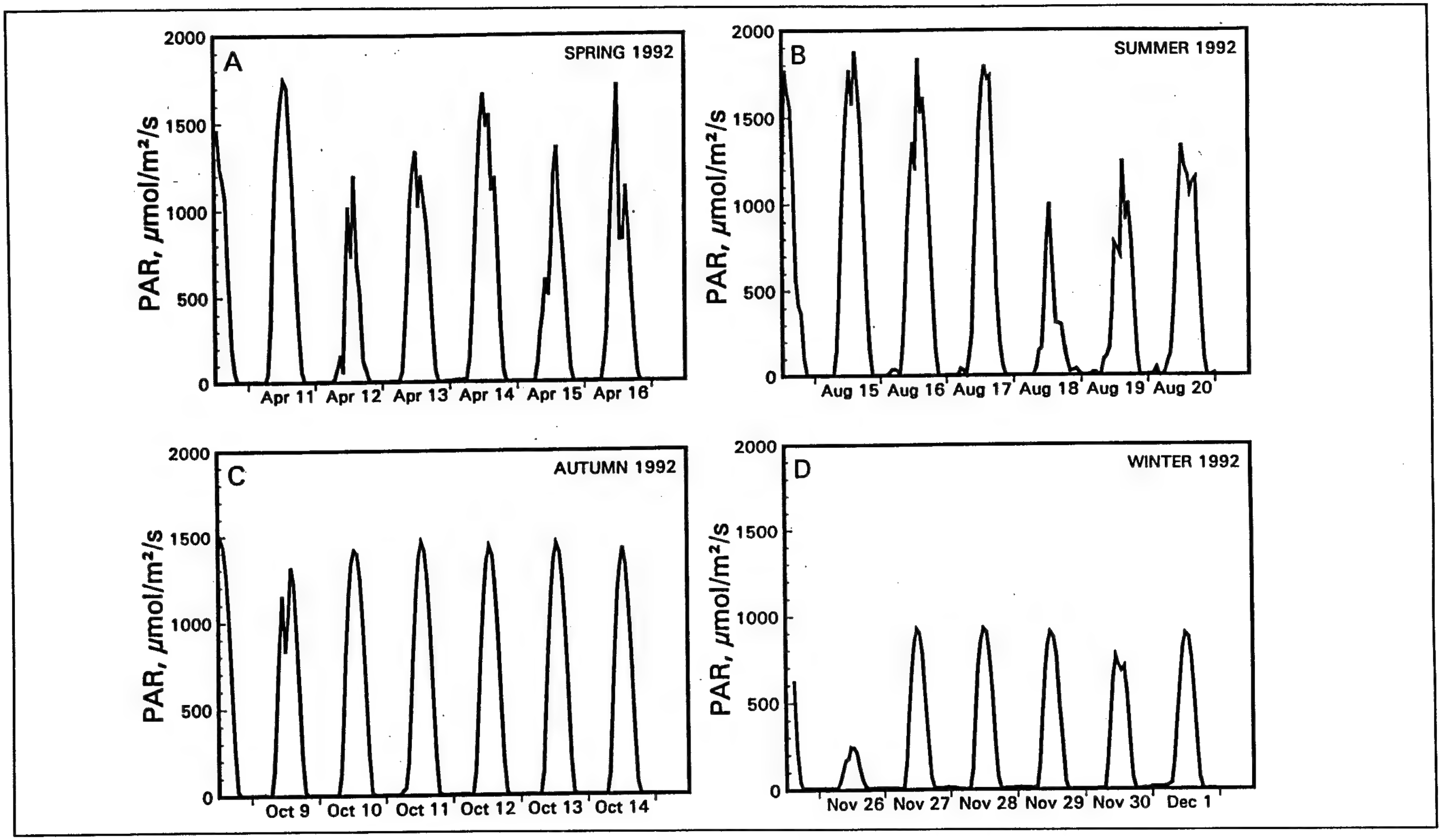

Figure 19. Hourly average photosynthetically active radiation (PAR) levels recorded by the LAERF meteorological station during selected 1-week water quality monitoring periods: A. spring, B. summer, C. autumn, and D. winter

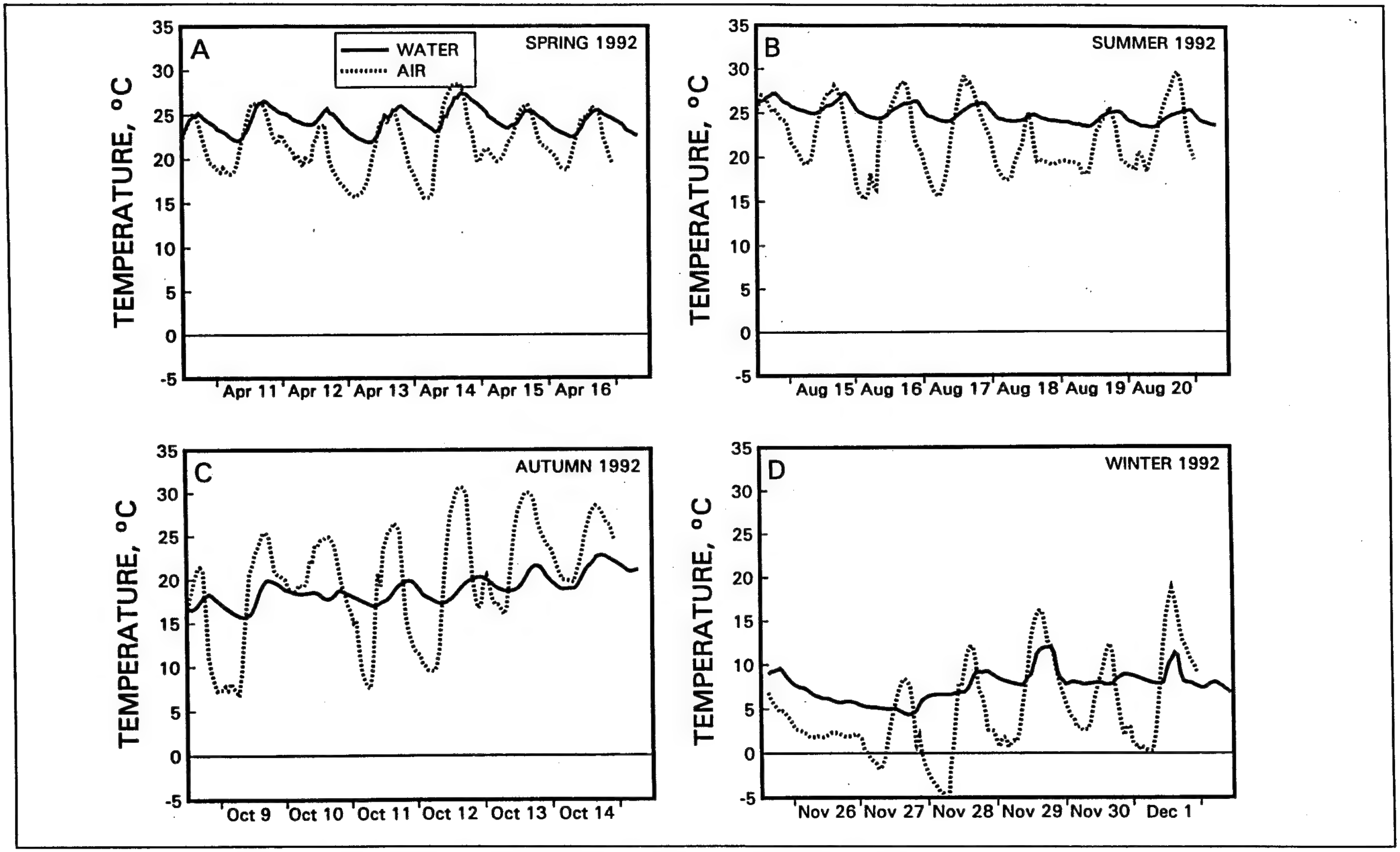

Figure 20. Hourly average air temperatures recorded by the LAERF meteorological station and hourly water temperatures recorded in a hydrilla culture pond (Pond 37) during: A. spring, B. summer, C. autumn, and D. winter water quality monitoring periods

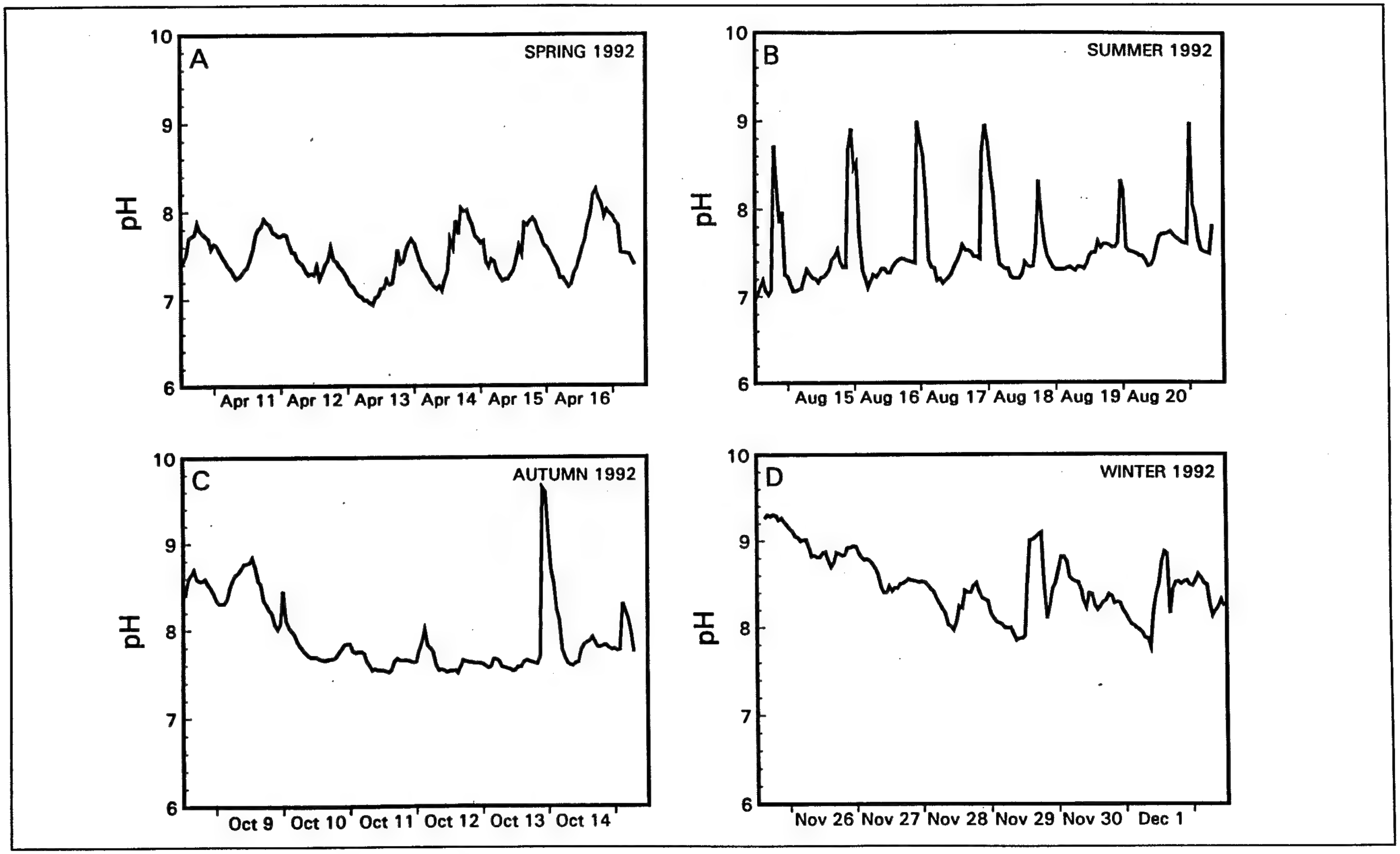

Figure 21. Hourly pH recorded in a hydrilla culture pond (Pond 37) during: A. spring, B. summer, C. autumn, and D. winter water quality monitoring periods

Conductivity can be affected by mineral nutrient uptake and by photosynthesis and respiration. Plant photosynthesis and respiration can affect conductivity either directly, by uptake or production of ionic species (HCO_3^-), or indirectly, by precipitation or dissolution of $CaCO_3$. Precipitation/dissolution of $CaCO_3$, since these involve both Ca^{++} and CO_3^{--} ions, exert a much stronger influence on conductivity.

Minor daily conductivity variations were observed during the spring monitoring period (Figure 22A). These changes were likely due to changes in pH and carbon speciation resulting from photosynthetic activity. However, during the summer monitoring period, diel patterns of conductivity included sharp declines and subsequent recoveries which coincided exactly with the rise and fall of pH (Figure 22B). These conductivity changes were due to precipitation of $CaCO_3$ during the day followed by redissolution at night. Conductivity did not exhibit regular daily variations during the autumn or winter monitoring periods (Figure 22C, 22D).

Dissolved oxygen concentrations in the pond changed widely both seasonally and diurnally. Levels of dissolved oxygen are affected by (a) the solubility of oxygen in water, which is controlled by temperature; (b) the exchange of oxygen across the air/water interface (which itself is affected by the concentration gradient between the air and the water, by the presence of a surface canopy (Honnell, Madsen, and Smart 1992; 1993), and by wind); and (c) the daily balance of photosynthesis and respiration. Respiratory activity includes plant maintenance respiration, respiration of aquatic organisms (such as fish and invertebrates) in the water column, and the respiration of heterotrophic organisms decomposing organic matter in or on the sediment.

The spring period was characterized by relatively high average dissolved oxygen levels with large diurnal oscillations (Figure 23A). The high average values during the spring are due to cool temperatures and a resultant high oxygen solubility, as well as to the lack of a surface canopy (which would have interfered with gas exchange). The large diurnal changes in dissolved oxygen are due to high metabolic rates of both phytoplankton and the developing hydrilla population. The importance of photosynthesis to the oxygen balance of the pond is demonstrated by the following example. Heavy cloud cover on April 12, 1992, reduced PAR (Figure 19A), resulting in reduced photosynthesis and the occurrence of significant oxygen depletion (to 1.5 mg/L) during the following night (Figure 23A).

In contrast with the patterns recorded for the spring monitoring period, during the summer and autumn monitoring periods (Figure 23B, 23C), dissolved oxygen levels were quite low, often below the 5 mg/L desirability threshold for warmwater fisheries (Boyd 1979). Indeed, dissolved oxygen levels recorded during both summer and autumn monitoring periods often remained below this critical value for the majority of each day, though for differing reasons. Full canopies of hydrilla during the summer monitoring period resulted in considerable self-shading, allowing only a small percentage of the plant biomass to receive adequate light for photosynthesis (Haller and

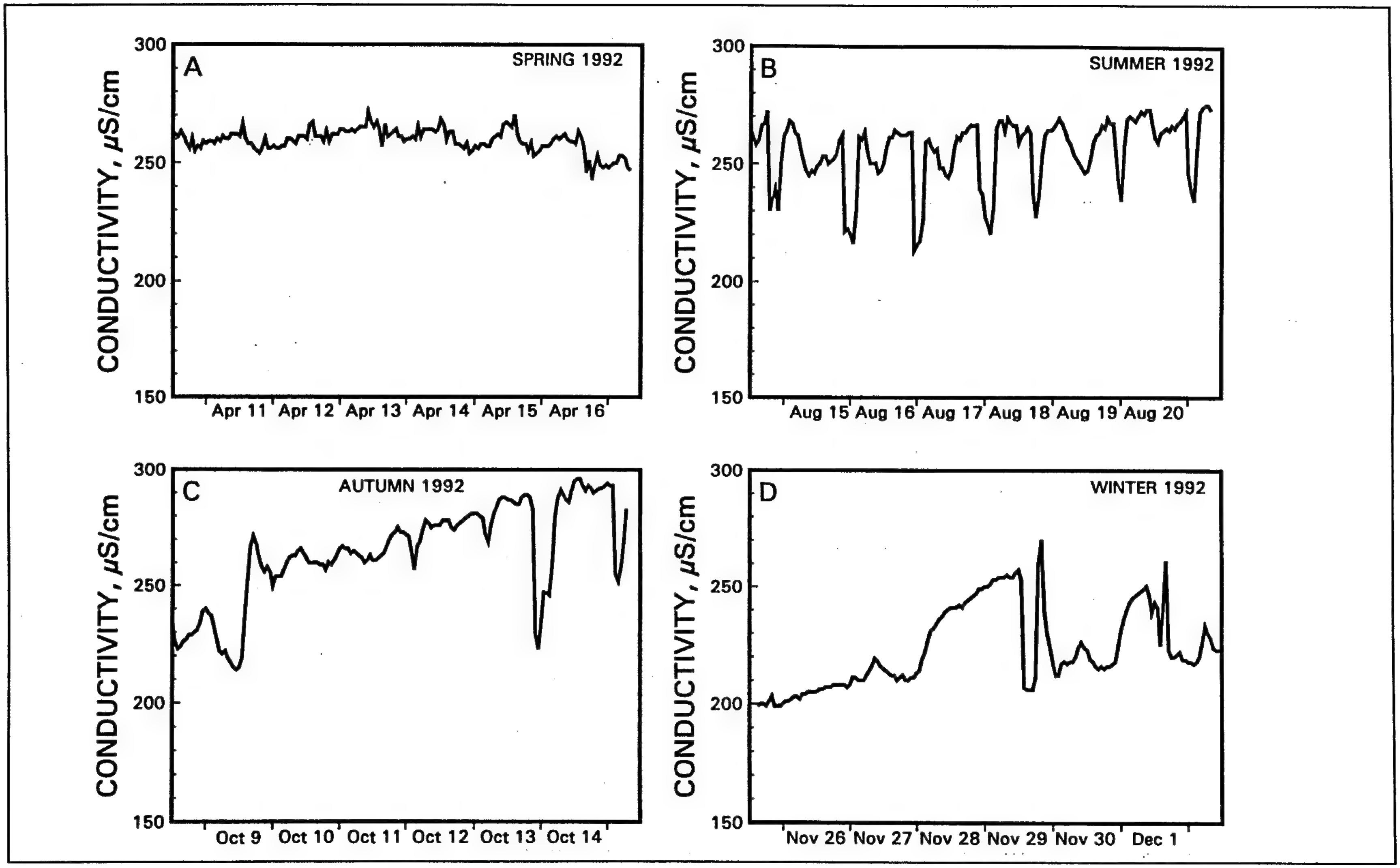

Figure 22. Hourly specific conductance (25 °C) measurements recorded in a hydrilla culture pond (Pond 37) during: A. spring, B. summer, C. autumn, and D. winter water quality monitoring periods

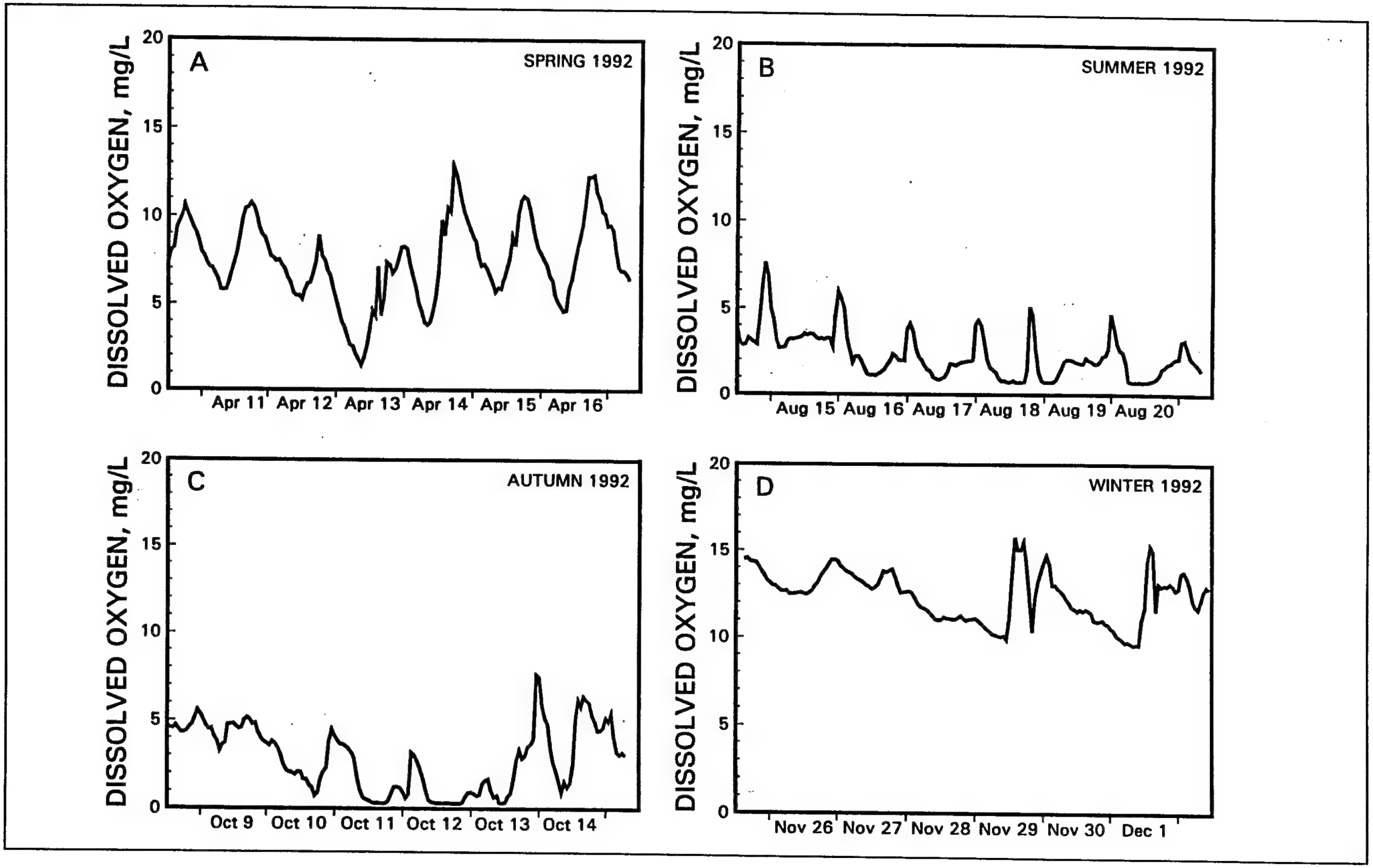

Figure 23. Hourly dissolved oxygen concentrations recorded in a hydrilla culture pond (Pond 37) during: A. spring, B. summer, C. autumn, and D. winter water quality monitoring periods

Sutton 1975). The remaining plant mass had a high-respiratory oxygen demand due to high summer temperatures (Figure 20B). These high temperatures, in concert with a well-developed surface mat, also limited the influx of atmospheric oxygen across the air/water interface, resulting in critically low (1 mg/L) dissolved oxygen levels (Honnell, Madsen, and Smart 1992, 1993). Although chronically low dissolved oxygen levels such as occurred in this hydrilla pond might not be suitable for conducting studies involving fish, oxygen levels in ponds vegetated with nonproblem species are more favorable (Honnell, Madsen, and Smart 1992, 1993).

Increases in dissolved oxygen during the daylight hours were not only relatively minor, they were also compressed into only a portion of the daylight period (note the sharp peaks in Figure 23B in comparison with the broad peaks in Figure 23A). This pattern, in conjunction with those for pH and conductivity, indicates that photosynthesis of the hydrilla canopy may have been limited by the availability of inorganic carbon during the summer monitoring period. Inorganic carbon limitation of photosynthesis in hydrilla may have contributed to the low levels of dissolved oxygen recorded in this pond.

As the plants began to senesce in autumn, decomposition of large amounts of dead plant material resulted in continued low dissolved oxygen levels (Figure 23C), even though oxygen solubility would have been increased by the lower autumn temperatures (Figure 20C). Although hydrilla was beginning to senesce during the autumn monitoring period, there was still a substantial surface mat which interfered with the exchange of oxygen across the air/water interface.

During the winter monitoring period, cold temperatures reduced respiration and decomposition rates, and further increased oxygen solubility, to the point that dissolved oxygen levels remained high throughout the day (Figure 23D).

Through photosynthetic and respiratory activity, and through the production of large amounts of biomass that will eventually decompose, some aquatic plants dramatically affect the seasonal and daily water quality of their environment.

7 Conclusions

The experimental ponds at the LAERF are well-suited for intermediate-scale research on many aquatic plant and wetlands issues. Sediments are fertile enough to support vigorous growth of rooted plants, but ponds do not typically produce midsummer algal blooms. Plant production (biomass) compares favorably with values recorded for other eutrophic aquatic systems. Water chemistry is also representative of a wide range of aquatic systems in the United States. Water quality can also be fairly easily altered to suit particular experimental requirements. The continental climate is also broadly representative of a wide range of sites within the United States. Although severe winters may kill tropical or semitropical free-floating species such as *Eichornnia crasippes* (waterhyacinth), all of the exotic submersed aquatic plants of national concern (and a great many native species) grow very well in the LAERF climate. Used in conjunction with mesocosm and laboratory research facilities, experimental pond studies provide a cost-effective intermediate step in the development of aquatic plant management methods for use in large, multipurpose reservoirs and waterways.

References

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. (1989). *Standard methods for the examination of water and wastewater*. 17th ed., American Public Health Association, Washington D.C.

Barko, J. W., and Smart, R. M. (1980). "Mobiliization of sediment phosphorus by submersed freshwater macrophytes," *Freshwater Biology* 10, 229-238.

_________. (1981). "Comparative influences of light and temperature on the growth and metabolism of submersed freshwater macrophytes," *Ecological Monographs* 51, 221-235.

_________. (1986). "Sediment-related mechanisms of growth limitation in submersed macrophytes," *Ecology* 67, 1328-1340.

Barko, J. W., Adams, M. S., and Clesceri, N. L. (1986). "Environmental factors and their consideration in the management of submersed aquatic vegetation: A review," *Journal of Aquatic Plant Management* 24, 1-10.

Barko, J. W., Smart, R. M., McFarland, D. G., and Chen, R. L. (1988). "Interrelationships between growth of *Hydrilla verticillata* (L.f.) Royle and sediment nutrient availability," *Aquatic Botany* 32, 205-216.

Boyd, C. E. (1979). *Water quality in warmwater fish ponds*. Agricultural Experiment Station, Auburn University, Auburn, AL.

Carter, V., Barko, J. W., Godshalk, G. L., and Rybicki, N. B. (1988). "Effects of submersed macrophytes on water quality in the tidal Potomac River, Maryland," *Journal of Freshwater Ecology* 4, 493-501.

Chambers, P. A., Hanson, J. M., Burke, J. M., and Prepas, E. E. (1990). "The impact of the crayfish *Orconectes virilis* on aquatic macrophytes," *Freshwater Biology* 24, 81-91.

Cooke, G. D., McComas, M. R., Waller, D. W., and Kennedy, R. H. (1977). "The occurrence of internal phosphorus loading in two small, eutrophic, glacial lakes in northeastern Ohio," *Hydrobiologia* 56, 129-135.

Day, P. R. (1956). "Particle fractionation and particle-saize analysis, Methods of soil analysis. Part I." *Agronomy* 9, 545-567, C. A. Black, et al. ed.

Dick, G. O., Getsinger, K. D., and Smart, R. M. (1993). "Design of a mesocosm system for conducting aquatic herbicide evaluations." *Proceedings, 27th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dick, G. O., and Smart, R. M. (1992). "Management of endemic aquatic macrophytes in warmwater ponds." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Doyle, R. D., and Smart, R. M. (1993). "Potential use of native aquatic plants for long-term control of problem aquatic plants in Guntersville Reservoir, Alabama, Report 1; Establishing native plants," Technical Report A-93-6., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Fuller, D. A., Sasser, C. E., Johnson, W. B., and Gosselink, J. G. (1985). "The effects of herbivory on vegetation on islands in Atchafalaya Bay, Louisiana," *Wetlands* 4, 105-114.

Haller, W. T., and Sutton, D. L. (1975). "Community structure and competition between hydrilla and vallisneria," *Hyacinth Control Journal* 13, 48-50.

Honnell, D. R., Madsen, J. D., and Smart, R. M. (1992). "Effect of aquatic plants on water quality in pond ecosystems." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1993). "Effects of selected exotic and native aquatic plant communities on water temperature and dissolved oxygen," Information Exchange Bulletin A-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Howard-Williams, C., and Allanson, B. R. (1981). "Phosphorus cycling in a dense *Potamogeton pectinatus* L. bed," *Oecologia* 49, 56-66.

Kleiner, J. (1988). "Coprecipitation of phosphate with calcite in lake water: A laboratory experiment modelling phosphorus removal with calcite in Lake Constance," *Water Research* 22, 1259-1265.

Lodge, D. M., and Lorman, J. G. (1987). "Reductions in submersed macrophyte biomass and species richness by the crayfish *Orconectes rusticus*," *Canadian Journal of Fisheries and Aquatic Science* 44, 591-597.

Lucas, W. J. (1983). "Photosynthetic assimilation of exogenous HCO_3^- by aquatic plants," *Annual Review of Plant Physiology* 34, 71-104.

Maberly, S. C., and Spence, D. H. N. (1983). "Photosynthetic inorganic carbon use by freshwater plants," *Journal of Ecology* 71, 705-734.

Madsen, J. D. (1993a). "Growth and biomass allocation patterns during waterhyacinth mat development," *Journal of Aquatic Plant Management* 31, 134-137.

________. (1993b). "Growth of waterhyacinth in North Texas." *Proceedings of the Texas Academy of Science* 96, 12-17.

Mulligan, H. F., and Baranowski, A. (1969). "Growth of phytoplankton and vascular aquatic plants at different nutrient levels," *Verh. Internat. Verein. Limnol* 17, 802-810.

Ondok, J. P., Pokorny, J. and Kvet, J. (1984). "Model of diurnal changes in oxygen, carbon dioxide and bicarbonate concentrations in a stand of *Elodea canadensis* Michx," *Aquatic Botany* 19, 293-305.

Otsuki, A., and Wetzel, R. G. (1972). "Co-precipitation of phosphate with carbonates in a marl lake," *Limnology and Oceanography* 17, 763-767.

Sand-Jensen, K., and Sondergaard, M. (1981). "Phytoplankton and epiphyte development and their shading effect on submerged macrophytes in lakes of different nutrient status," *Int Rev ges Hydrobiol* 66, 529-552.

Smart, R. M. (1990). "An overview of competition studies and the development of the Lewisville Aquatic Plant Research Facility." *Proceedings, 24th Annual Meeting, Aquatic Plant Control Research Program*. Miscellaneous Paper A-90-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

________. (1991a). "Lewisville Aquatic Ecosystem Research Facility: Progress report." *Proceedings, 25th Annual Meeting, Aquatic Plant Control Research Program*. Miscellaneous Paper A-91-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M. (1991b). "Aquatic plant competition studies." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-91-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1992a). "Lewisville Aquatic Ecosystem Research Facility: An update." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1992b). "Aquatic plant competition studies in Guntersville Reservoir." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1993). "Further developments at the Lewisville Aquatic Ecosystem Research Facility." *Proceedings, 27th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1994a). "Annual report of the Lewisville Aquatic Ecosystem Research Facility." *Proceedings, 28th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-94-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1994b). "Progress report on plant competition studies." *Proceedings, 28th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-94-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M., and Barko, J. W. (1985). "Laboratory culture of submersed freshwater macrophytes on natural sediments," *Aquatic Botany* 21, 251-263.

__________. (1986). "Effects of water chemistry on aquatic plants: Growth and photosynthesis of *Myriophyllum spicatum* L," Technical Report A-86-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1988). "Effects of water chemistry on aquatic plants: Interrelationships among biomass production, plant nutrition, and water chemistry," Technical Report A-88-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M., Barko, J. W., and McFarland, D. G. (1994). "Competition between *Hydrilla verticillata* and *Vallisneria americana* under different environmental conditions," Technical Report A-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M., and Decell, J. L. (1994). "Aquatic plant research at Lewisville Aquatic Ecosystem Research Facility," Aquatic Plant Control Research Program Information Exchange Bulletin A-94-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smart, R. M., Snow, J. R., and Dick, G. O. (1992). "Environmental characteristics of ponds at the Lewisville Aquatic Ecosystem Research Facility." *Proceedings, 26th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-92-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stewart, R. M., and Monteleone S. E. (1993). "Investigation of submersed plant regrowth under low light levels." *Proceedings, 27th Annual Meeting, Aquatic Plant Control Research Program.* Miscellaneous Paper A-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stumm, W., and Morgan, J. J. (1981). *Aquatic chemistry: An introduction emphasizing chemical equilibria in natural waters.* New York.

Titus, J. E., and Adams, M. S. (1979). "Coexistence and the comparative light relations of the submersed macrophytes *Myriophyllum spicatum* L. and *Vallisneria americana* Michx," *Oecologia* 40, 273-286.

Titus, J. E., and Stephens, M. D. (1983). "Neighbor influences and seasonal growth patterns for *Vallisneria americana* in a mesotrophic lake," *Oecologia* 56, 23-29.

Van, T. K., Haller, W. T., and Bowes, G. (1976). "Comparison of the photosynthetic characteristics of three submersed aquatic plants," *Plant Physiology* 58, 761-768.

Wetzel, R. G. (1975). *Limnology.* W. B. Saunders, Philadelphia, PA.

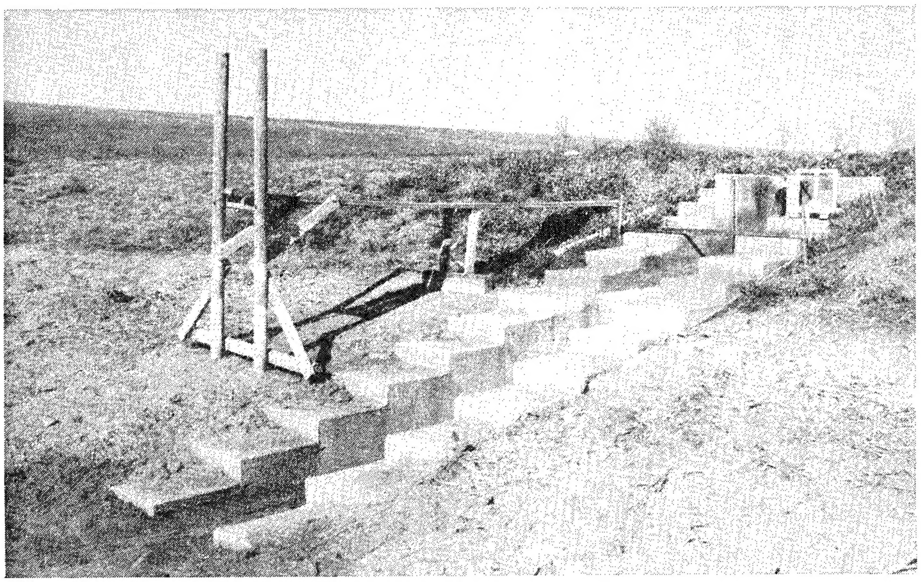

Photo 1. Drain box of a typical LAERF pond

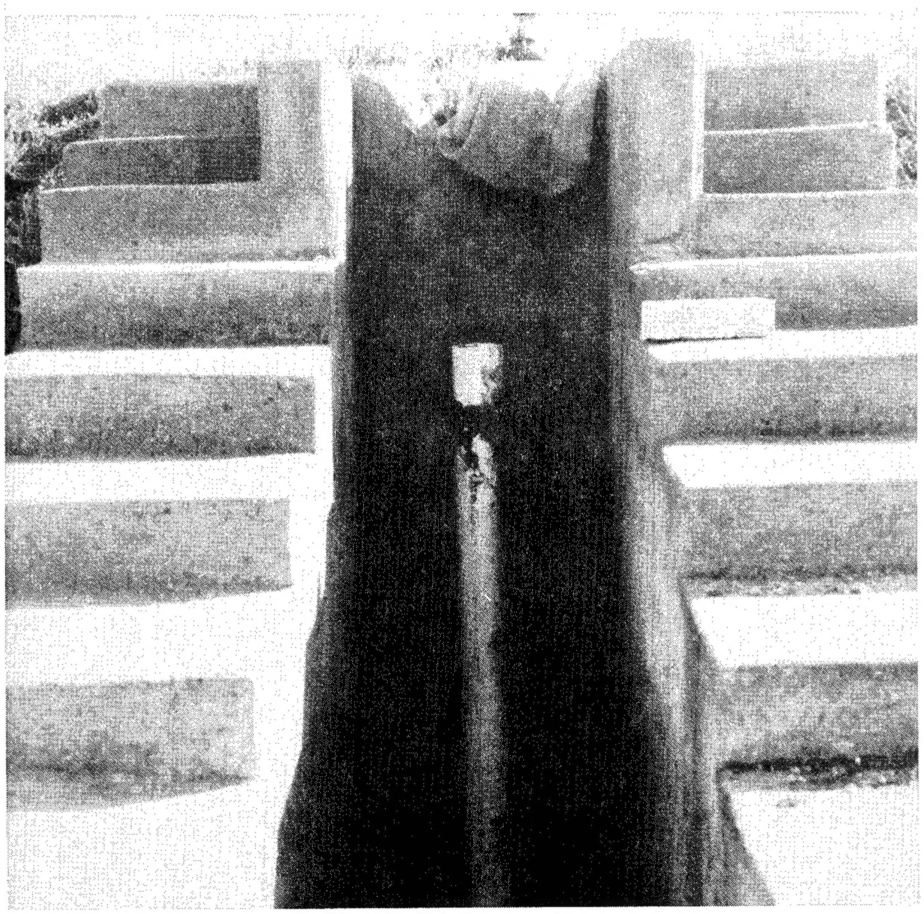

Photo 2. Stand-pipe drain in a typical LAERF pond

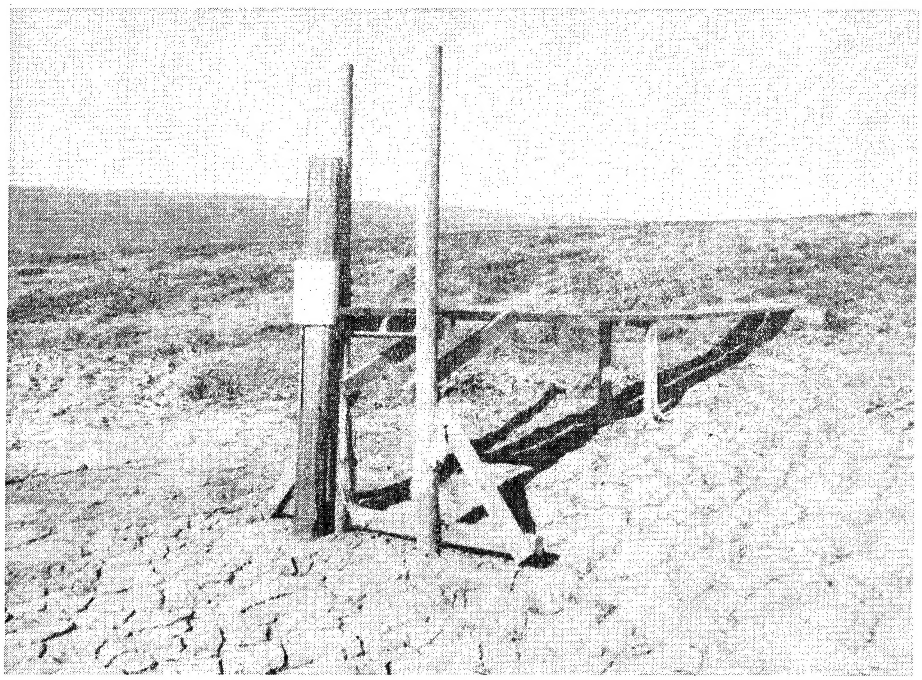

Photo 3. Sampling pier in a typical LAERF pond. Note the screened exclosure for obtaining integrated water samples without disturbing the vegetation

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13. ABSTRACT *(Maximum 200 words)*

This report describes physical and environmental characteristics of experimental ponds located at the Lewisville Aquatic Ecosystem Research Facility (LAERF). Daily average air temperatures and daily maximum levels of photosynthetically active radiation (PAR) recorded during 1992 are presented as representative of meteorological conditions occurring at LAERF. Physical dimensions, capacities, and design specifications of the ponds is provided. Daily average temperatures of pond water and sediment are also presented for 1992. Diurnal changes in PAR levels measured at different depths in a representative pond are presented. Composition and fertility of pond bottom sediments are discussed in relation to requirements for the growth of rooted submersed aquatic plants. The extant flora and fauna of the LAERF are considered in relation to their possible influence on use of the ponds for aquatic plant research. The chemical composition of the pond water supply and a representative hydrilla pond is presented over a period encompassing two growing seasons. Diurnal changes in temperature, pH, conductivity, and dissolved oxygen in the same hydrilla pond are also presented for 1-week periods representative of each of the four seasons. The LAERF ponds are suitable for conducting a variety of aquatic plant studies.

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